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DOCTORAL THESIS

Measuring Productivity
– Concepts and Evidence from Norway

Author

Thomas VON BRASCH

Supervisors

Karen Helene ULLTVEIT-MOE

Ådne CAPPELEN

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Contents

Acknowledgements	i
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1 Introduction	1
1.1 An overview of productivity measurement	3
1.2 Chapter 2: The Norwegian productivity puzzle – not so puzzling after all?	8
1.3 Chapter 3: Understanding the productivity slowdown: the importance of exit and entry of workers	9
1.4 Chapter 4: The import price index with trade barriers: theory and evidence	11
1.5 Chapter 5: Identifying the sector bias of technical change	14
1.6 Concluding remarks	15
 2 The Norwegian productivity puzzle – not so puzzling after all?	 17
2.1 Introduction	17
2.2 Related literature	19
2.3 Comparing the level of productivity across countries	20
2.3.1 The Tableau effect	23
2.3.2 The nominal exchange rate as a proxy for relative net export prices	25
2.3.3 Is the first premise of the Norwegian productivity puzzle real? . .	27
2.4 Comparing productivity growth across countries	29
2.4.1 Econometric specification	30
2.4.2 Data description	31
2.4.3 Results	36
2.5 Conclusions	40
 3 Understanding the productivity slowdown: the importance of exit and entry of workers	 42
3.1 Introduction	42
3.2 Biases of standard practice	45
3.2.1 Decomposing hours worked	47
3.2.2 Defining the “true” index	47
3.2.3 Decomposing the biases of entering and exiting workers	52
3.2.4 The two-step procedure – controlling for worker characteristics . .	54

3.3	Data	57
3.4	Empirical results	59
3.4.1	Decomposing labour costs using the standard practice	59
3.4.2	Comparing standard practice with other classical indices	61
3.4.3	Comparing standard practice with the true index	63
3.4.4	The two-step procedure – controlling for the level of education	63
3.4.5	Robustness with respect to the elasticity of substitution	65
3.4.6	Implications for productivity measurement	66
3.5	Conclusions	67
4	The import price index with trade barriers: theory and evidence	68
4.1	Introduction	68
4.2	Measuring import prices	70
4.2.1	The standard import price index	72
4.2.2	An import price index with trade barriers	73
4.3	The bias of the standard import price index	77
4.4	Empirical application	81
4.5	Conclusions	85
5	Identifying the sector bias of technical change	87
5.1	Introduction	87
5.2	The sector bias of technical change	89
5.3	Econometric framework	91
5.3.1	Framework used in the literature	91
5.3.2	Identifying SBTC	92
5.3.3	Identifying TFP growth	97
5.3.4	Identifying a sector bias of SBTC	97
5.3.5	Identifying a sector bias of TFP	98
5.4	Data description	98
5.5	Econometric results	102
5.5.1	Identifying SBTC	102
5.5.2	Identifying a sector bias of SBTC	105
5.5.3	Identifying a sector bias of TFP	109
5.6	Conclusions	110
	References	111
A	Appendix to Chapter 2	122
A.1	The Èltetö-Köves-Szulc (EKS) index	122
A.2	PPPs for capital input	123
A.3	Mapping from ISIC Rev. 2 to ISIC Rev. 3	123
A.4	Mapping from ISIC Rev. 3 to ISIC Rev. 4	124

B	Appendix to Chapter 3	128
B.1	Approximation of unit value biases	128
B.2	Two-step biases	129
B.3	Contractual hours as a proxy for actual hours worked	130
C	Appendix to Chapter 4	134
C.1	The bias in import prices due to trade barriers when goods are perfect substitutes	134
C.2	Proof: Proposition 4.1	134
C.3	Proof: Proposition 4.2	136
D	Appendix to Chapter 5	138
D.1	Translog cost function	138
D.2	Additional tables	140

Chapter 1

Introduction

“Productivity isn’t everything, but in the long run it is almost everything”

— Paul Krugman

“The heart of science is measurement”

— Erik Brynjolfsson

Productivity is a main determinant of economic development. In fact, it is by many regarded as the single most important determinant of welfare. Loosely speaking, productivity growth is defined as the ability to produce more for less. Growth in productivity is thus the result of, inter alia, improved products, processes, services, technologies, ideas and organisational structure. It follows that productivity growth leads to economic growth, which further yields higher income and usually increased welfare.

To enhance productivity it is necessary to identify the correspondence between possible determinants and productivity. During the last decades a vast literature has been trying to identify the drivers of economic growth. Some of the main findings suggest that the level of R&D, the skill level of the labour force, the distance to the technological frontier and institutions, such as the political system, are important determinants of productivity, see e.g., Wolff (2014).

The quotes from Brynjolfsson and Krugman are taken from Lohr (2013) and Krugman (1997, p. 11), respectively.

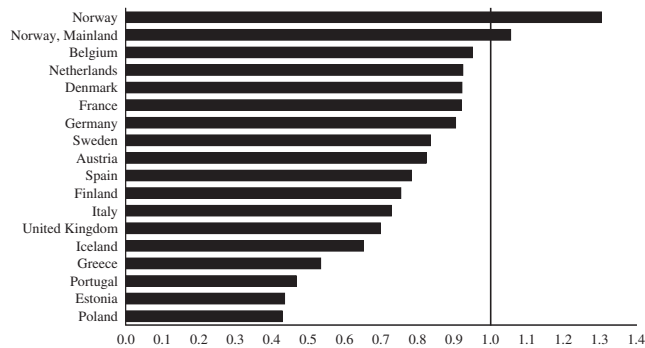


FIGURE 1.1: Labour productivity. Measured as GDP per hour worked relative to the United States in 2013. Converted using current PPPs for the total economy. Sources: OECD and Statistics Norway. Mainland Norway consists of all domestic production activity except oil and gas extraction including services, transport via pipelines and ocean transport.

Even though much has been learned about the general determinants of productivity, many questions are still unanswered and new questions arise. To illustrate, consider the two different measures of productivity provided in Figure 1.1 and Figure 1.2. Figure 1.1 compares the *level* of labour productivity across countries. In particular, it shows GDP per hour worked, relative to the United States, for a group of OECD countries in 2013. According to this measure, labour productivity in Norway as well as in Mainland Norway are higher than in all the other countries. Figure 1.2 shows the index for labour productivity over time for Mainland Norway and the group of seven countries (G7) consisting of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States. From the early 1990s Norway experienced an increased growth rate in labour productivity and a higher growth than in G7 lasting until 2005. In 2005 labour productivity growth was reduced both in Norway and across the G7 countries. Labour productivity declined in Norway from 2007 to 2009, before increasing again thereafter.

Several important questions arise from Figure 1.1 and Figure 1.2. Why is the measured level of productivity in Norway so high compared with other countries? Was the growth in productivity from the mid 1990s to 2005 exceptionally high and what caused the slump in productivity from 2005? How has the increased level of productivity impacted the economy? Have technological changes impacted skilled and unskilled labour equally, or has the shift in production technology favoured some educational groups more than others? Are there any sectors of the economy that have been particularly exposed to technological change? The purpose of my thesis is to answer these questions. As will be shown, much of the answers can be found within the theory of measurement. Hence, to form a point of reference from which my thesis evolves, I proceed this introductory

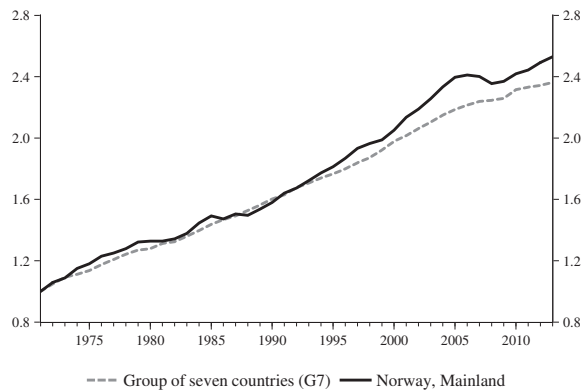


FIGURE 1.2: Labour productivity. Measured as GDP per hour worked (1971=1). Sources: OECD and Statistics Norway. Mainland Norway consists of all domestic production activity except oil and gas extraction including services, transport via pipelines and ocean transport. The group of seven countries (G7) consists of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.

chapter with a short overview of productivity measurement followed by a summary of the four main chapters of the thesis and concluding remarks.

1.1 An overview of productivity measurement

Productivity is commonly defined as the ratio of outputs to inputs, both terms measured in volumes. For example, labour productivity can be defined as value added per unit of labour. A challenge with measuring productivity is that the *value* of output and the *value* of labour are observable, while the *volume* of output and the *volume* of labour must be measured with the aid of price indices. To be specific, let VY denote value added in current prices and VL denote labour in current prices. Moreover, let P_Y and P_L represent price indices for value added and labour, respectively. It then follows that a measure for labour productivity can be written

$$\text{Labour productivity} = \frac{VY/P_Y}{VL/P_L}. \quad (1.1)$$

The importance of measurement for productivity analysis can be seen from Equation 1.1. It is not only value added and labour in *current prices* that need to be measured, but also *price indices* for value added and labour must be calculated to measure labour productivity. Measuring aggregate price changes is thus crucial to identify productivity.

How to combine numerous price changes into an aggregate index for price changes is the basic index number problem. Calculating a total index is not trivial as it involves the aggregation of numerous prices of potentially very heterogeneous items. Because the price changes of these items usually differ, a formula to aggregate the individual price changes to an overall index is needed. In Figure 1.1 and Figure 1.2, the Drobisch price index was used to measure labour services. However, given the choice between several different index formulas, such as Laspeyres, Paasche, Dutot, Törnqvist, Fisher or Drobisch, a relevant question is: what objective criteria should be applied when deciding on what index number to use?

Two types of criteria are widely applied: axiomatic and economic. The axiomatic approach is based on a number of objective tests. For example, the *Proportionality* axiom implies that if all prices change by the same common factor, the price index should also change by that factor. The *Identity* axiom states that if prices do not change between time periods neither should the overall price index. The *Commensurability* axiom states that the price index should be invariant to changes in the units of measurement. The *Monotonicity* axiom states that the price index should increase if there are one or more price increases in the current period but there are no price declines. The *Factor reversal* axiom states that if a price index is multiplied with its corresponding quantity index the product should equal the ratio of values for the two comparison periods.

A thorough discussion of these and many more axioms can be found in e.g., The Consumer Price Index Manual (ILO et al., 2004b). It turns out that the Fisher index is the only index number that satisfies all of the 20 axiomatic tests that are discussed in what is labelled the first axiomatic approach. In comparison, the Törnqvist index passes 11 of these tests (ILO et al., 2004b, p. 297). In contrast, in what is labelled the second axiomatic approach, where a price index is defined by two sets of prices and two sets of values (and not quantities), it is the Törnqvist index that passes all of the axiomatic tests.

There are several practical problems with the axiomatic approaches. It is not clear what criteria to use to weight the different tests and how to decide on which of the two axiomatic approaches to use. Also, any given list of axioms can be viewed as arbitrary. Moreover, even if an index fails a particular test, it does not necessarily imply that using this index will result in a large error. Nevertheless, the Fisher and the Törnqvist indices stand out as superior to many of the other indices in the first and second axiomatic approach, respectively. Also, these indices tend to behave similarly as they both use information about value shares in both comparison periods.

Using an economic criterion as a basis for evaluating price indices dates back to Konüs

(1939). The purpose of the economic approach is to yield an index that shows the change in the cost-of-living between two time periods for a given level of utility. Interestingly, both the Fisher and the Törnqvist indices also score high when assessed by economic criteria. In a seminal article by Diewert (1976) it was shown that these indices are superlative, i.e., they are consistent with the change in cost-of-living when the economic framework is approximated with second-order accuracy. In particular, the Törnqvist index is exact if the cost function in the economic system is of translog form. Since both the Fisher and the Törnqvist index score high on both axiomatic and economic test criteria they are considered by many to be superior indices.

Despite desirable properties of the Fisher and the Törnqvist indices, other indices are often used in practical work due to lack of data. For example, when measuring labour productivity, a unit value index, also referred to as a Drobisch index, is used to calculate the contribution from labour, see e.g., the OECD Productivity Database (OECD, 2013, p. 66).

There are also cases other than data availability that prevents the use of the Fisher and the Törnqvist indices, or any other standard price index for that matter. For example, consider the case when a new product is released to the market at time t . In this case, there is a price observation at time t , but there is no price observation at time $t - 1$. Since standard indices rely on price information at both comparison periods, these indices cannot be applied in the case of new goods. If one wait until period t before the good is included in the price index, the initial welfare gain between period $t - 1$ and t is unaccounted for, a bias referred to by the Boskin commission as the *new goods bias* (Boskin et al., 1996). In terms of labour services, the new good bias is tantamount to the bias of not taking into account the effect of workers entering the labour force.

There are also cases where it is feasible to apply indices, but where the economic and axiomatic criteria yield different conclusions regarding which index to choose. In the standard cases mentioned above, such as with the Fisher and Törnqvist indices, the price level is unimportant for the development of the index. But the price level can become important for costs of imports during say a gradual process of trade liberalisation. An increased supply of low cost goods and services lowers the costs of imports, *ceteris paribus*. This implies that even if prices are unchanged, a lowering of trade barriers will lead to lower costs of imports. It can be accounted for in an economic framework, but any index that accounts for such lower costs must violate the identity axiom.

Equation 1.1 can also be used to illustrate the calculation and comparison of productivity levels between countries. So far, the interpretation of the indices P_Y and P_L has been in a temporal context, i.e., between time periods. However, they could equally well

represent spatial indices showing the relative price levels between countries. If P_Y and P_L are spatial indices measuring the price level difference between say Norway and United States, the productivity index in Equation 1.1 shows Norway's level of labour productivity measured in USD. Applying Equation 1.1 to several countries allows for comparison of productivity levels since the index is measured in a common set of prices, see Figure 1.1.

A problem with the pure index approach, as represented by Equation 1.1, is the lack of theoretical foundations. For example, the index number obtained by applying Equation 1.1 does not provide any information about what type of technical change that has occurred. Solow (1957) used an economic framework for productivity analysis to shed light on the structure of technical change. The starting point was a general aggregate value added (Y) production function of capital (K) and labour (L)

$$Y = f(K, L, \mathbf{z}),$$

where the variables are measured in constant prices, i.e., $Y = VY/P_Y$, $K = VK/P_K$ and $L = VL/P_L$. For expositional purposes capital and labour are presented as aggregates, but they could also be split into sub-aggregates. For example, capital could be split into capital objects such as land, buildings and motor vehicles, whereas labour could be split into groups according to the level of education. The vector $\mathbf{z} = (z_1, z_2, \dots, z_n)$ consists of n technology variables. These variables capture any kind of shift in the production function caused by, inter alia, changes in the R&D capital stock, political institutions, skill level of the labour force, efficiency of which the factors of production are utilised and the organisation of production. To isolate the impact from technological changes on production, it is convenient to rewrite the production function assuming a translog functional form

$$\ln Y = \ln a + a_K \ln K + a_L \ln L, \quad (1.2)$$

where the second order effects except the cross products are excluded. In this specification, the technology variables in \mathbf{z} have now been mapped into three new variables representing two types of technological change: neutral and factor biased. The term a represents factor neutral technical change and it is a log linear function of the technology variables \mathbf{z} . Factor biased technical change is represented by the terms a_K and a_L , which also are log linear functions of the underlying technology variables. There is a large literature analysing the effect from factor biased technical change on important economic variables such as wages and employment, see e.g., Acemoglu and Autor (2011). There exists also a literature analysing if the sectors where factor biased technical change occurs matter for the impact on wages and employment, the so called sector bias of factor

biased technical change hypothesis, see e.g., Haskel and Slaughter (2002).

Total factor productivity growth is the portion of output growth not explained by labour and capital growth. It can be measured using the Törnqvist index, which is consistent with Equation 1.2. Total factor productivity growth is affected both by factor neutral and factor biased technical change, and it is consequently dependent on the technology variables in \mathbf{z} . There is a large literature trying to identify which variables that are causing productivity growth and should be included in the vector \mathbf{z} , see Hall et al. (2010); Hulten (2010); Syverson (2011); Wolff (2014) for some recent overviews on this literature.

My thesis builds on the concepts of measurement outlined above using Norway as an illustrative example. In Chapter 2, the growth in productivity is analysed across countries taking both the distance to the technological frontier, R&D and human capital into account. Also, the spatial price index used to calculate overall productivity in Norway in Figure 1.1 will be analysed and compared with alternatives. In particular, it is shown that Norway's level of productivity by many measures are not as high as Figure 1.1 shows, a result which is traced back to the measurement of the spatial price index for value added. In Chapter 3, it is shown that about a quarter of the slowdown in productivity after 2005, illustrated in Figure 1.2, can be explained by the use of hours worked as an index for labour services. A central part of the analysis deals with the bias caused by workers entering and exiting the workforce. Using a more appropriate index than hours worked reduces labour services approximately between 1 to 2 percentage points annually. The backdrop of Chapter 4 is the hypothesis that mismeasurement of import prices has contributed to the particularly high measured level of productivity growth in Wholesale and retail trade, an industry which has been a main driver of overall productivity growth in Norway from the beginning of the 1990s. It will be shown how mismeasurement of import prices leads to mismeasured productivity due to the calculating procedures in the National Accounts. An economic approach to deal with the impact from trade liberalisation on import prices is thus proposed in Chapter 4 and the procedure is illustrated using the example of clothing imports to Norway. In Chapter 5, the framework typically used to measure factor biased technical change is critically evaluated, and it is shown in the case of Norway that making too many simplifying assumptions when measuring factor biased technical change may yield biased results. In the following sections a more detailed summary of the findings from each chapter is presented.

1.2 Chapter 2: The Norwegian productivity puzzle – not so puzzling after all?

In standard economic textbooks on economic growth, such as Acemoglu (2009, p. 12), Jones and Vollrath (2013, p. 278), Weil (2013, p. 186) or Ros (2013, p. 410), we can read about measures indicating that Norway enjoys one of the highest levels of productivity in the world. Such a high level of productivity level seems puzzling when compared with the relatively low aggregate level of R&D investments in Norway. As stated in the opening lines of OECDs Economic Survey: “There is a puzzle about Norway. How did it succeed in reaching one of the highest living standards among OECD countries from a relatively poor ranking in 1970?” (OECD, 2007a, p. 18). It is not only the level of living standards, or productivity, that is high, but also the growth in productivity has been high in Norway. According to OECD “the Norwegian puzzle is that despite weak innovation inputs and even weaker outputs, Norwegian per capita incomes are very high by international comparison, even excluding petroleum earnings. Furthermore, the level and growth rate of total factor productivity – TFP – has been respectable by international comparison” (2007a, p. 125). Moreover, it is stated that “Productivity is high, real growth rates have been respectable, overall TFP growth is better than in many countries with higher R&D spending, and industry has by and large managed to survive a changing world and a strong exchange rate.” (OECD, 2007a, p. 129).

The first aim of Chapter 2 is to analyse if the *level* of productivity in Norway is really as high as reported statistics suggest. I find that using Purchasing Power Parities (PPP) with a recent base year can significantly overestimate the level of productivity in Norway. The reason is that net exports is deflated directly in the calculation of overall expenditure PPPs. However, the contributions from exports and imports should be deflated separately since net exports can take upon both positive and negative values. Using export and import price indices relative to the US, I show that a separate deflation of exports and imports can account for most of the difference between constant and current PPPs between 1997 and 2010. When using PPPs with a base year in 1997, i.e., before the surge in Norway’s terms of trade began, the productivity level in Norway is on par with the levels in Sweden and France in 2005, but around 7 and 3 per cent lower than in the USA and Germany, respectively.

The second aim of Chapter 2 is to analyse if there is a puzzle underlying the relatively high productivity *growth* in Norway beginning in the mid 1990s. To analyse if the high growth rate represents a puzzle, I estimate a model that takes into account the level of human capital, R&D capital stock and the distance to the technological frontier. If there really is a puzzle about productivity in Norway one would expect the unexplained

growth in productivity to be significantly higher in Norway compared with other countries. I show that unexplained productivity growth between 1995 and 2005 is quite evenly distributed across countries. For Norway the result is clearly within one standard deviation from the mean unexplained rate of TFP growth across countries. Thus, based on these results there is no reason to claim that the development of productivity in Norway represents a puzzle.

1.3 Chapter 3: Understanding the productivity slowdown: the importance of exit and entry of workers¹

Many OECD countries have experienced a measured slowdown in labor productivity from 2005 and onwards. Norway is no exception in this respect. While the average productivity growth was 2.7 percent between 2002 and 2005, it dropped markedly after 2005 and reached -1.4 per cent in 2008, see Figure 1.2. This productivity slowdown occurred in tandem with a massive increase in immigration following the 2004 enlargement of the European Union. The ratio of net immigration to the total number of employees almost tripled from a level of about 0.6 before 2005 to 1.7 in 2008. Several other European countries have experienced a similar surge in immigration after 2005.

The negative correlation between net immigration and productivity growth raises a particular concern with respect to how productivity is measured. Labour productivity growth is defined as the ratio of the index for value added to the index for labour services. It is standard practice to use the change in hours worked as a proxy for the labour services index. However, it is well known that hours worked represents a biased proxy for labour services. The reason is that a worker's contribution to labour services should be weighted by his or her cost to the firm, not the share of hours worked. For example, if there are a large number of low paid immigrants entering the labour market after 2005, and if wages reflect marginal productivity, a measure of labour services based on hours worked would overstate the contribution to labour services and consequently understate the true development in productivity.

The bias between using hours worked and a more theoretically based index for labour services, such as Fisher or Törnqvist, is referred to as the unit value bias. In a more general context, the unit value bias has been discussed extensively in the literature, see e.g., Párniczky (1974); Timmer (1996); Balk (1998b) and Silver (2010). Diewert and Lippe (2010) summarise many of these findings and analyse the unit value bias more explicitly with respect to the Laspeyres, the Paasche and the Fisher price indices.

¹This chapter was written together with Ådne Cappelen and Diana-Cristina Iancu.

To counteract the weaknesses of using hours worked it is common to control for worker characteristics in a two-step procedure: the first step defines groups by worker characteristics and the second step aggregates hours worked across these groups using an index with good theoretical and axiomatic properties such as Törnqvist or Fisher, see e.g., Jorgenson et al. (1987), Jorgenson et al. (2005), Cao et al. (2009) and work based on the EU KLEMS database such as O'Mahony and Timmer (2009); Timmer et al. (2010). Based on this framework Zoghi (2010) discusses the use of predicted wages in calculating the weighting scheme, which is the current practice at the U.S. Bureau of Labor Statistics. Using data for Norway, Hægeland (1997) calculated labour services using register data and classifications of workers according to education and sex. Nilsen et al. (2011), analysed productivity across manufacturing industries in Norway also using register data and categorised employed persons into 12 subgroups. They added to this literature by using weights based on an estimate of predicted wages associated with individual skill attributes.

The theoretical rationale for the two-step procedure can be found in Párnitzky (1974) and Diewert and Lippe (2010). They show that the unit value bias decreases with increased disaggregation if it is compositional effects between the groups that contribute most to the overall bias. However, if compositional effects within groups are dominant, disaggregation may increase the unit value bias. Note that these theoretical results follow from comparing the change in hours worked relative to indices that require underlying prices and quantities to be defined in both the base and the comparison period, such as the Fisher and Törnqvist indices. But, when applying hours worked to calculate labour services, this proxy is also calculated across those workers that were only present in *either* the comparison period or the base period. The unit value bias should consequently be defined relative to an index that allows for workers entering and exiting the labour market, a property which becomes increasingly important when net immigration surges.

In this chapter, we generalise the results from Párnitzky (1974) and Diewert and Lippe (2010) to allow for workers entering and exiting the labour market. To this end, we build on the theory of Feenstra (1994) who analysed the impact of new product varieties on import prices when the underlying cost function was of constant elasticity of substitution (CES) form. These theoretical results and some generalisations can also be found in Balk (1999). Using the case of perfect substitutes as a benchmark, we show that the contribution from entering and exiting workers on the unit value bias depends on the unit value of entering and exiting workers relative to the unit value of continuing workers. We also show theoretically that controlling for worker characteristics in the two-step procedure can exacerbate the unit value bias through entering and exiting effects.

Using Norwegian register data spanning the years 2002 to 2008, we empirically decompose the contributions from workers entering and exiting employment and those that are continuously employed. To our knowledge, this is the first study on how entry and exit effects impact aggregate wages, labour services and consequently the measure of productivity. We find that the standard practice of using hours worked overestimates labour services by approximately between 1 to 2 percentage points annually from 2002 to 2008. Correspondingly, wages and productivity are thus underestimated by between 1 to 2 percentage points annually. About half is attributed to a bias among continuing workers and half is attributed to the effect of workers entering and exiting employment. We also find that controlling for the level of education in the two-step procedure exacerbates the unit value bias in most years.

The backdrop of this chapter is the hypothesis that mismeasurement can explain parts of the observed drop in productivity growth in Norway after 2005. On average, productivity grew 2.7 per cent annually in mainland Norway between 2002 and 2005. Between 2006 and 2008 average annual growth reduced to 0.2 percent, down by about 2.5 percentage points. We show that the bias from using hours worked as a measure for labour services, compared to an index of labour services with desirable properties in line with index theory, increases on average with 0.7 percentage points annually after 2005. Most of this bias is due to an increasing number of entering workers with a relatively low wage rate, a development that must be seen in conjunction with the surge in immigration after 2005. Mismeasurement of productivity can thus explain about a quarter of the measured productivity slowdown after 2005.

1.4 Chapter 4: The import price index with trade barriers: theory and evidence

Although Chapter 2 shows there is no reason to claim that the development of productivity in Norway represents a puzzle, the sizeable productivity growth in the Wholesale and retail trade industry (henceforth WRT industry) is still largely unexplained. The backdrop of Chapter 4 is the hypothesis that mismeasurement of import prices has contributed to the high level of productivity growth in the WRT industry. It is well known that mismeasurement of import prices may lead to mismeasurement of productivity in general. As shown in Feenstra et al. (2013b), the import price index is used to deflate nominal value added, which is the output measure often used to calculate productivity. As the following example illustrates, a mismeasurement of import prices will, due to the calculating procedures of the National Accounts at Statistics Norway, also impact productivity in the WRT industry specifically. It will not impact production in the

WRT industry, but it will impact the level of intermediates, and hence the level of value added, and thereby also the level of productivity.

To illustrate the link between import prices and productivity, consider how value added in the WRT industry is calculated in the National Accounts at Statistics Norway.² Let X , Y and R denote production, value added and intermediates, respectively, measured in *current* prices. Moreover, let P denote a price index. For example, if $P_X = 1.05$, the price level of production is 5 per cent higher than in the comparison period.

Production in the WRT industry, often referred to as the value of trade margins, is defined as the difference between the purchasers' value of sales (S) and the basic value of costs (B), i.e., $X = S - B$ (when ignoring net taxes). Since there exists no measured price index to deflate trade margins it is assumed that the volume of trade margins grow proportionally with the sale of underlying products. However, if the measured purchasers' price and the measured basic price deviate in such a manner that the identity between trade margins, the purchasers' price and the basic price is violated, then the National Accounts department adjusts trade margins based on the statistics found to be most reliable. As there is no measured price index for production in the WRT industry, it is the current value of production that is adjusted. Specifically, production is deflated using purchasers' prices, i.e., X/P_S . This method ensures that production in *constant* prices is independent of the basic price. Moreover, the basic price index is used to create an *adjusted* level of the basic value $\tilde{B} = B (P_B/P_S)$, where the adjusted level is marked by a wide tilde. As a result, the adjusted production is given by

$$\begin{aligned}\tilde{X} &= S - \tilde{B} \\ &= S - B (P_B/P_S).\end{aligned}$$

Accordingly, the adjusted production is decreasing in the measured level of basic prices. Generally, basic prices is a weighted average of domestic and *import prices* of all commodities traded through the WRT industry. Hence, mismeasured import prices that show too high a growth rate leads to a lower production in the WRT industry.

Although production in *constant prices* is independent of the basic price index, value added in constant prices is still affected when using this adjustment procedure. To see this, consider how value added is constructed. Since there exist statistics on operating margins and wages underlying the current price estimate of value added, the adjusted current price estimate of intermediates is measured as the difference between adjusted

²Thanks are due to Steinar Todsén for providing me with this example. Note that the National Accounts department tries to override unreasonable effects on value added caused by the adjustment procedure by calibrating the volume of intermediates or production.

production and value added, i.e.,

$$\begin{aligned}\tilde{R} &= \tilde{X} - Y \\ &= S - B(P_B/P_S) - Y,\end{aligned}$$

which is decreasing in basic prices. Since there exist reliable statistics on the prices of intermediates, the constant price estimate is measured by deflating the current price estimate with the price index of intermediates \tilde{R}/P_R . The constant price estimate of intermediates is therefore a decreasing function of the measured basic price. As a result, value added in constant prices, measured as the difference between production and intermediates

$$X/P_S - \tilde{R}/P_R,$$

is an increasing function of the measured basic price. Consequently, even though production is not affected by mismeasured basic prices, if basic prices wrongly show too high a growth rate, the measured value added in the WRT industry will be also too high. Consistent with this example, the average annual growth in value added in the WRT industry between 1995 and 2010 was 1.2 percentage points higher than the average annual growth in production.

Since the basic price depends on the import price of the product, mismeasurement of import prices can lead to serious mismeasurement of productivity. The results from the example above raise the question: under what circumstances will the import price index be overestimated?

In Chapter 4 it is shown why import prices can be overestimated during times of trade liberalisation. The starting point is the strong assumption of free trade underlying standard price indices. If the assumption is true, the price *level* of a particular good is irrelevant for the development of the price index. However, if goods are not traded freely, which is often the case in practice, the price level becomes important for the final index number. Hence, neglecting the price level can lead to serious mismeasurement of import prices. To circumvent this problem it is common in the literature to use average prices as an aggregator formula. However, average prices may still underestimate the cost of imports effects from trade liberalisation. In this chapter, I generalise the import price index to allow for barriers to trade in the form of quantity constraints and develop an upper bound index to the true index. To illustrate the theoretical framework, I use the case of clothing imports to Norway for which have undergone massive trade liberalisation during the last two decades, and show that the Laspeyres price index overestimates the true cost-of-imports annual inflation rate by 1.5 percentage points

between 1988 and 2005. I also show that a unit value index, which is believed to be appropriate for the aggregation of homogenous items, overestimates the annual inflation rate by 0.5 percentage points when goods are perfect substitutes. The results of the article thus point to mismeasurement of import prices as a potential source underlying the high productivity growth measured in the Wholesale and retail trade industry.

1.5 Chapter 5: Identifying the sector bias of technical change³

The theory of skill-biased technical change (SBTC) has been linked to the increase in the wage premium and/or the increase in the relative unemployment rates between high- and low-skilled labour observed in most OECD countries in the past three decades. If technical change is directed at high skilled, and if high and low skilled labour are substitutes, the increased demand for high skilled labour can lead to either an increase in the relative wage rate or a decrease in the relative unemployment rate between the two factors of production, see Acemoglu (2009, p. 500). In the literature on SBTC there is an ongoing debate concerning the importance of a sector bias of SBTC. While the SBTC hypothesis is based on the relative profitability between factors of production, the sector bias hypothesis focuses on the relative profitability between sectors. For example, if the proportion of high-skilled labour varies across sectors, it is not clear that skill-biased technical change will lead to a higher wage premium. If technical change favours skilled labour in a sector where the proportion of skilled labour is low, this will increase the profitability of the sector where technical change takes place. Even if technical change were directed at the high-skilled, because technical change took place in a sector dominated by low-skilled labour, this would lead to an increase in demand of low-skilled labour and consequently a lowering of the wage premium. In other words, the skill intensity of the sector where technical change occurs matters for the development of the wage premium. This theoretical result is well known and dates back to at least Findlay and Grubert (1959).

The empirical literature studying sector bias of technical change has only focused on skill-biased technical change. The purpose of Chapter 5 is to analyse if sector bias of *both* factor-neutral and factor-biased technical change can explain the changing relative unemployment rates between high and low skilled labour in Norway. Using data from 1972 to 2007, the empirical evidence is not clear on the impact of a sector bias of skill-biased technical change, but it points to a sector bias of factor-neutral technical change from the 1970s to the 1990s. That said, the impact of the sector bias seems to have

³This chapter has been published in Empirical Economics, see Brasch (2015).

gradually reduced towards the latter part of the sample period. I also evaluate the cross-section model used in the literature and show that strong restrictions must be placed on a vector equilibrium correction model to end up with this model. If these restrictions do not hold, the results reported in the literature may be biased. I show that these restrictions are strongly rejected, and erroneously imposing them significantly change the estimates of skill-biased technical change in many sectors. The results from the Oil and gas exploration sector shed light on two general problems with the framework used in the literature. It is shown that what is interpreted as equilibrium correction in the vector equilibrium correction model is wrongfully interpreted as SBTC in the cross-section model. Also, assuming high- and low-skilled labour to be either substitutes or complements leads to a large bias of SBTC. By using a vector equilibrium correction model, the pitfalls of the cross-section model can be avoided.

1.6 Concluding remarks

The purpose of this thesis has been to analyse some important concepts of productivity measurement and relate them to the case of Norway. This thesis shows the importance of correctly measuring productivity both across countries and across time. In particular, the high measured level of productivity in Norway is questioned, and the treatment of net exports is pointed to as a potential source of the discrepancy between the levels of productivity when using different base years. Moreover, what has been labelled a *Norwegian productivity puzzle*, i.e., the combination of high productivity and a low level of determinants of productivity, is shown not to be present when taking R&D, distance to the technological frontier and the skill intensity into account. In addition, it has also been shown that adjusting for compositional effects in the measurement of labour services yields approximately between 1 to 2 percentage points higher productivity growth annually from 2002 to 2008. Adjusting for compositional effects also explains about a quarter of the productivity slowdown after 2005. This thesis also points to a potential mismeasurement of productivity in the Wholesale and retail trade industry, which according to official statistics has experienced an exceptionally high rate of productivity from the beginning of the 1990s. It is shown that a mismeasurement of import prices leads to a higher measured rate of productivity, and that the measurement of import prices during times of trade liberalisation is likely to be biased. Furthermore, it is shown that factor biased technical change is not the only theory consistent with the changes in relative unemployment and wages across educational groups observed during the last decades. Differences in technological advances across sectors, the so called sector bias of technical change hypothesis, is identified as a plausible driving force, in particular from the 1970s until the mid-1990s.

Although this thesis answers some specific questions regarding measurement of productivity, many questions are still largely unexplained, and new questions arise. For example, although the model in Chapter 2 accounts for important determinants of productivity growth, some of the productivity growth is still unexplained and further research is needed to identify additional determinants. Also, the production structure must be relatively equal between countries to compare productivity levels. However, Norway is a large producer of products that our neighbouring countries do not produce much of, such as aluminium, fish and offshore equipment. To take into account the different production structures across countries one would need to study the production processes at the product level in each country. In Chapter 3, the importance of compositional effects for the measurement of labour productivity is illustrated. It was implicitly assumed that the flow of labour services from each worker changed only through changes in hours worked. However, experience also matters for growth in labour services. Taking account of experience is left for future research and could be analysed within the framework of hedonic indices. In Chapter 4, the proposed index based on quantity restrictions to account for cost reductions during periods of trade liberalisation raises some practical concerns. In particular, it can be difficult to evaluate when and to what extent quantity restrictions are present, and hence, if the proposed index should be applied instead of a standard price index. The framework proposed in Chapter 4 also begs a question with respect to the results from Chapter 3. If the increased immigration after 2005 is caused by the 2004 enlargement of the European Union and is thus a result from trade liberalisation, should not the framework outlined in Chapter 4 be used to analyse the impact from immigration on labour services in Chapter 3? In Chapter 5, the impact of technological change on relative wages and unemployment is analysed in terms of a deterministic trend. However, for policy analysis, it is important to also identify what types of technological change that cause changes in relative wages and unemployment. The abovementioned questions are some of those that arise from this thesis. Hence, the quotation by Øksendal (2003) puts the findings of this thesis in its right perspective:

We have not succeeded in answering all our problems. The answers we have found only serve to raise a whole set of new questions. In some ways we feel we are as confused as ever, but we believe we are confused on a higher level and about more important things.

Chapter 2

The Norwegian productivity puzzle – not so puzzling after all?

Abstract: The Norwegian productivity puzzle is rooted in three seemingly contradictory “facts”: First, Norway is one of the most productive OECD countries. Second, Norway has experienced high growth in productivity. Third, Norway has a relatively low level of R&D intensity. In this chapter, I show that the first premise of the puzzle is probably false. Explicitly, I demonstrate that labour productivity in Norway is not particularly high when using production purchasing power parities instead of expenditure purchasing power parities to measure mainland GDP in a common currency. The gap between the two measures is traced back to the use of market exchange rates as proxies for relative net export prices in the calculation of expenditure PPPs. In addition, I show that the high growth rate in productivity can be explained by an empirical growth model that takes both R&D capital, human capital and the distance to the technological frontier into account. Based on these results, there is no reason to claim that the development of productivity in Norway represents a puzzle.

2.1 Introduction

In standard economic textbooks on economic growth, such as Acemoglu (2009, p. 12), Jones and Vollrath (2013, p. 278), Weil (2013, p. 186) or Ros (2013, p. 410), we can read about measures indicating that Norway enjoys one of the highest levels of productivity in the world. Some of these measures, such as those provided by OECD, Penn World Table (Heston et al., 2012; Feenstra et al., 2013a) and The Total Economy Database (The Conference Board, 2014), are based on gross domestic product (GDP) for the whole economy and include petroleum extraction. Since much of petroleum extraction is the collection of economic rent, these measures overestimate the true level of productivity. That said, the level of productivity in Norway is still reported to be higher than in

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other countries when controlling for the petroleum extraction industry. For example, Statistics Norway reported the level of productivity to be between 20 and 30 per cent higher than in Denmark, Sweden, Finland, Germany and France in 2010, see Statistics Norway (2013, p. 46). Also, OECD reported the Norwegian GDP per worker in the mainland economy to be about 10 to 20 per cent higher than in the abovementioned countries in 2005 (OECD, 2007a, Figure 1.1.B, p. 19).

Such high productivity levels seem puzzling when compared with the relatively low aggregate level of R&D investments in Norway. As stated in the opening lines of OECDs Economic Survey: “There is a puzzle about Norway. How did it succeed in reaching one of the highest living standards among OECD countries from a relatively poor ranking in 1970?” (OECD, 2007a, p. 18). It is not only the level of living standards, or productivity, that is high, but also the growth in productivity has been high in Norway. According to OECD “the Norwegian puzzle is that despite weak innovation inputs and even weaker outputs, Norwegian per capita incomes are very high by international comparison, even excluding petroleum earnings. Furthermore, the level and growth rate of total factor productivity – TFP – have been respectable by international comparison” (2007a, p. 125). Moreover, it is stated that “Productivity is high, real growth rates have been respectable, overall TFP growth is better than in many countries with higher R&D spending, and industry has by and large managed to survive a changing world and a strong exchange rate.” (OECD, 2007a, p. 129).

The purpose of this chapter is twofold. The first aim is to analyse if the *level* of productivity in Norway is really as high as reported statistics suggest. I find that using Purchasing Power Parities (PPP) with a recent base year can significantly overestimate the level of productivity in Norway. The reason is that net exports is deflated directly in the calculation of overall expenditure PPPs (Eurostat and OECD, 2012, Section 12.39). However, the contributions from exports and imports should be deflated separately since net exports can take upon both positive and negative values. Using export and import price indices relative to the US, I show that a separate deflation of exports and imports can account for most of the difference between constant and current PPPs between 1997 and 2010. When using PPPs with a base year in 1997, i.e., before the surge in Norway’s terms of trade began, the productivity level in Norway is on par with the levels in Sweden and France in 2005, but around 7 and 3 per cent lower than in the USA and Germany, respectively.

The second aim of the chapter is to analyse if there is a puzzle underlying the relatively high productivity *growth* in Norway beginning in the mid 1990s. To analyse if the high growth rate represents a puzzle, I estimate a model that takes into account the level of human capital, R&D capital stock and the distance to the technological

frontier by means of panel data techniques. The functional form of the model represents a hybrid between the models in Griffith et al. (2004), Cameron et al. (2005) and Coe et al. (2009). If there really is a puzzle about productivity in Norway one would expect the unexplained growth in productivity to be significantly higher in Norway compared with other countries. I show that unexplained productivity growth between 1995 and 2005 is quite evenly distributed across countries. For Norway the result is clearly within one standard deviation from the mean unexplained rate of TFP growth across countries. Thus, based on these results there is no reason to claim that the development of productivity in Norway represents a puzzle.

The rest of the chapter is organised as follows. In Section 2.2, related literature regarding both the level and growth in productivity in Norway is discussed. In Section 2.3, the level of productivity in Norway is analysed, with a particular focus on the construction of PPPs. In Section 2.4, productivity growth in Norway from 1995 to 2005 is analysed. I outline the econometric framework and the main results are presented. The last section concludes.

2.2 Related literature

The Norwegian productivity puzzle, sometimes also referred to as the Norwegian paradox, has spurred research trying to explain it. With this puzzle in mind, Grønning et al. (2008), Fagerberg et al. (2009) and Asheim (2012) point to different aspects of the Norwegian national system of innovation. In contrast, Castellacci (2008) claims that the source of the paradox lies not with innovative activities, but it has rather to do with the sectoral composition of the economy.

Several international studies analysing productivity use total GDP which includes the petroleum industry. Recently Feenstra et al. (2009) propose a new method to measure real GDP from the production side by modifying real GDP from the expenditure side to include differences in terms of trade between countries. Madsen et al. (2010) use aggregate data for Norway and show that R&D intensity, the interaction with distance to the frontier, educational attainment-based absorptive capacity, and technology gap positively influence TFP growth.

By focusing at the industry level the problems related to measuring productivity in the petroleum sector can be avoided. Griffith et al. (2004) analyse productivity across 15 manufacturing industries in a panel of OECD countries from the beginning of the 1970s to 1990. To convert value added in domestic currency to US dollars they use an economy wide PPP. However, since relative prices can vary greatly between countries

and industries, using a common PPP across all industries could distort the estimate of the technological frontier. To account for this Griffith et al. (2004) also use disaggregated industry specific PPPs for 7 of the OECD countries in their sample, but not for Norway. For those countries where industry specific PPP data were not available they adjust the whole economy PPP by the average ratio across countries of the industry-specific to the whole economy PPP in a particular industry.

The studies by Griffith et al. (2004), Kneller (2005) and Kneller and Stevens (2006) were conducted using data on a limited set of manufacturing industries and the sample ended before the acceleration of Norway's productivity growth began. More recent data are needed to analyse the underlying causes of this surge in measured productivity growth.

Within the EU KLEMS project there has been extensive research efforts to provide production PPPs at the industry level. Inklaar and Timmer (2013) outline the procedure needed to adjust PPPs for final domestic demand to output PPPs and Inklaar and Timmer (2008) provide detailed information about the Productivity Level Database at the Groningen Growth and Development Centre. Unfortunately, data for Norway are currently not included in the Productivity Level Database. However, Timmer et al. (2006) did provide production PPPs at the industry level for the benchmark year 1997 also for Norway. These output PPPs are a mixture of adjusted expenditure PPPs and production PPPs where the weighting between the two methods is based on the quality and availability of data. The results from the present study are based on the production PPPs provided by Timmer et al. (2006).

2.3 Comparing the level of productivity across countries

In this section I analyse if the *level* of productivity in Norway, measured as GDP per hour worked, is really as high as reported statistics suggest. The analysis will focus on the choice of PPPs used to measure GDP in a common currency.

There are different concepts of PPPs that can be applied, for example current or constant PPPs. Current PPPs at time t refers to PPPs generated from a price survey at time t . In contrast, the term constant PPPs at time t refers to the PPPs from a price survey at a particular base year and then extrapolated to time t using relative temporal price indices between countries. When comparing productivity across countries over time it is constant PPPs that should be used since they capture volume changes only, whereas current PPPs capture both volume and price changes.

Since the level of productivity refers to the ratio of output to inputs in real terms, a PPP that yields the ratio of real value added (Y_{jt}/Y_{kt}) between country j and k at time t is preferred. To illustrate, let $P_{jt}Y_{jt}$ be value added measured in current prices in country j . If data on value added in current prices in both countries are available, the use of a purchasing power parity that represents the price ratio of value added between country j and k , $PPP_{jkt} = P_{jt}/P_{kt}$, yields the desired result

$$\frac{(P_{jt}Y_{jt})}{(PPP_{jkt})(P_{kt}Y_{kt})} = \left(\frac{Y_{jt}}{Y_{kt}}\right). \quad (2.1)$$

This expression illustrates that PPPs are not only price deflators, but also currency converters if value added in country j and k is measured in different currencies. Equation 2.1 also shows why an exchange rate is not suitable for comparisons of productivity: since an exchange rate fluctuates due to for example investors' sentiments, government intervention and capital flows between countries, there is no reason why an exchange rate should equal the price ratio of value added between the two countries at all time periods.

The measured level of productivity is directly impacted by the choice of PPPs when applying Equation 2.1. It is therefore important which PPP that is used for productivity analysis. In the following I will compare the PPPs provided by the Eurostat-OECD PPP Programme and a set of PPPs provided by Timmer et al. (2006). The purpose of the Eurostat-OECD PPP Programme is to create PPPs for value added across countries. Theoretically, they can be constructed from either the production or the expenditure side. Due to data availability they are constructed from the expenditure side and cover consumption, investment and net exports for the whole economy. These PPPs are suitable if the purpose is to study aggregate productivity. However, if the purpose is to analyse productivity at the industry level or to control for the impact from the petroleum industry, production PPPs at the industry level are required (Eurostat and OECD, 2012, Section 1.2.2). Timmer et al. (2006) have made available a dataset with PPPs for industry output that includes Norway. It is constructed from both PPPs based on producer prices and on adjusted PPPs based on purchasers' prices. To derive an output price from a domestic expenditure prices they make adjustments for margins and taxes, international trade prices and an adjustment for intermediate consumption. They provide PPPs at a two digit industry level. To get PPPs at a more aggregate level, I follow their work and apply the Èltetö-Köves-Szulc (EKS) method to aggregate PPPs across industries and countries in the base year 1997.⁴ The EKS method is also used to aggregate PPPs by OECD and Eurostat (2012). To calculate the PPPs from Timmer et al. (2006) for other years than the base year I extend the PPPs from the base year

⁴See the appendix, Section A.1 for details regarding the computation of the EKS index.

using the relative price index for value added between countries. More explicitly, for a given base year $t = b$, the PPP between country j and country k , for all time periods t , is calculated as

$$PPP_{jkt} = PPP_{jkb} \frac{(P_{jt}/P_{jb})}{(P_{kt}/P_{kb})}. \quad (2.2)$$

where (P_{jt}/P_{jb}) and (P_{kt}/P_{kb}) are the temporal price indices for value added in country j and k , respectively. This way of constructing PPPs is often referred to as “constant PPPs” and it preserves the domestic volume growth rates when applying Equation 2.1 over time. Relative productivity is thus measured with respect to a constant base year b .

Figure 2.1 compares the expenditure PPP from OECD and the aggregated PPPs based on Timmer et al. (2006), both for all industries and when excluding the petroleum and computer industries.⁵ The current expenditure PPP from OECD is converted to basic prices by multiplying with the relative ratio of GDP measured at basic and purchasers’ prices between Norway and USA.⁶ In 1997, the production PPP for all industries and the production PPP for all industries except petroleum and computers are 10.2 per cent and 6.8 per cent higher than the PPP from OECD, when measured by NOK/USD. Using the PPPs from Timmer et al. (2006) would thus lead to a lower measured relative level of productivity for Norway. Before 1995 there is a close correspondence between the PPPs provided by OECD and the PPPs based on Timmer et al. (2006). The reason why there is so little discrepancy between these series is due to how OECD has calculated the PPPs. Prior to 1995, PPPs for all countries have been backdated using the relative rates of inflation between countries as measured by their implicit price deflators for GDP.⁷ The series labeled current PPPs by OECD thus represent constant PPPs prior to 1995. After 1998 there is a widening gap between the different measures of PPPs.

⁵Isic Rev. 4 codes d05t09 (Mining and quarrying) and d26 (Computer, electronic and optical products). Mining and quarrying has been excluded since much of the value added from this industry is the collection of economic rent. To study relative productivity levels, the portion of an industry’s value added being economic rent should be excluded. Excluding the computer, electronic and optical products industry does not change the overall picture much, but this industry has been excluded since for some countries, the growth in value added has been extremely high. It is therefore possible that differences in productivity for this industry are mainly caused by differences across countries in dividing the current price estimate into a price index and a constant price estimate. For example, the value added deflator in Sweden went from 52.7 in 1993 to 1 in 2005. From estimates based on the US intermediate input price deflators from semiconductors and microprocessors, Edquist (2005) concludes that the productivity growth of the Swedish Radio, television and communication equipment industry during the 1990s is an artefact, see also Edquist (2013).

⁶The PPP from OECD in basic prices NOK/USD is calculated as $PPP^B = PPP^P \left(\frac{GDP_{NOR}^B / GDP_{NOR}^P}{GDP_{USA}^B / GDP_{USA}^P} \right)$, where GDP is the value of gross domestic product and the superscripts P and B refer to purchasers’ and basic prices, respectively.

⁷See www.oecd.org/std/ppp/faq.

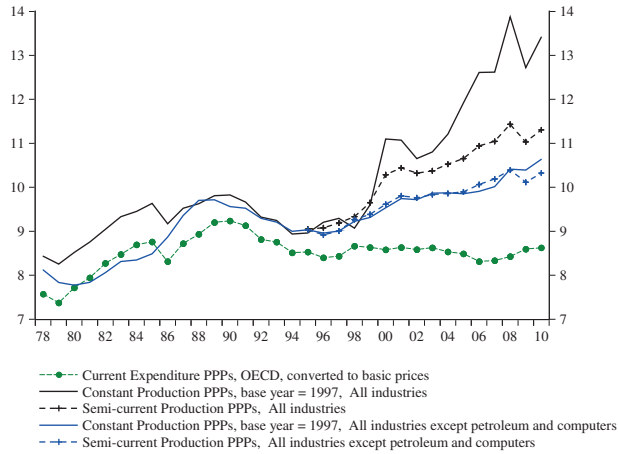


FIGURE 2.1: Expenditure and production PPPs measured in basic prices, NOK/USD. Sources: OECD and Timmer et al. (2006), author's calculations. Constant Production PPPs are generated by first applying the EKS index at the lower industry level to create an aggregate PPP and then using Equation 2.2 to create a time series at the aggregate level. In contrast, the Semi-current Production PPPs are generated by first using Equation 2.2 to create time series for PPPs at the lower industry level, and then aggregate using the EKS index. The current expenditure PPP from OECD is converted to basic prices by multiplying with the relative ratio of GDP measured at basic and purchasers' prices between Norway and USA.

There are several potential explanations for the large gap between constant and current PPPs. It could be due to differences across countries in creating price indices and different frameworks in the creation of national accounts and in the creation of PPPs. For example, there are differences in how countries adjust for quality changes in the construction of price indices. Since the U.S. Bureau of Economic Analysis uses hedonic methods extensively to account for quality changes, the price changes in the U.S. GDP deflator will be lower than in countries not taking into account quality changes, all other things equal (McCarthy, 2013), potentially causing a gap between extrapolated PPPs and current PPPs relative to the U.S. In the following, I will consider two other explanations for the large and widening gap: the so called “Tableau effect” and the treatment of net exports in the creation aggregate PPPs.

2.3.1 The Tableau effect

A potential reason for the widening gap is the difference in weighting schemes applied when constructing current and constant PPPs. If there are large differences in industry structure over time, the PPPs based on data in 2005 will potentially differ from the PPPs

calculated in 1997 and extrapolated to 2005 using Equation 2.2. To illustrate, consider the following example: There are two goods and two countries, and the price of the two goods is the same in both countries at all time periods. Thus, the current PPP equals unity in all time periods. Further, assume that country j almost only produces one of the goods, say petroleum, and that the price of this good has increased by 5 per cent since the base year. As country j almost only produces petroleum, the aggregate price index is approximately equal to $P_{jt}/P_{jb} = 1.05$. Symmetrically, assume that the other good is almost only produced in country k and that the price is unchanged across time periods: $P_{kt}/P_{kb} = 1$. In contrast to the spatial price index which yields a PPP equal to unity at time t , the constant PPP one gets from applying Equation 2.2 equals 1.05. The problem arises since current PPPs are based on common weights whereas constant PPPs are based on national weights. While current PPPs measure the aggregate relative price of the same goods in different countries, the constant PPPs are also influenced by price changes of the goods that countries produce relatively much or little of. This example illustrates how the choice of currency converter for productivity analysis typically depends on the base year chosen, a well known result dubbed the “tableau effect” by Summers and Heston (1991, p. 340). Unfortunately, it is not possible to measure the size of the tableau effect directly since current production PPP data are not available. However, it is possible to construct a semi-current production PPP from a two digit industry level using the data from Timmer et al. (2006). As pointed out above, the construction of constant PPPs was done in two steps: first applying the EKS index at the lower industry level and then using Equation 2.2 to create a time series at the aggregate level. In contrast, the semi-current production PPPs is generated by first using Equation 2.2 to create time series for PPPs at the lower industry level, and then aggregate using the EKS index. Any price structure shift at the lower industry level is then accounted for.

Figure 2.1 shows semi-current production PPPs for both all industries and all industries except petroleum and computers measured in Norwegian Kroner per US dollars. The deviation between the constant and semi-current PPPs for all industries is large, reflecting the sizeable increase in the petroleum price after 2000. In contrast, for most of the years the deviations between the constant and semi-current PPPs when subtracting the petroleum and computers industries are within 1 per cent. The change in price structure between industries at the two-digit level is therefore not able to explain the difference between constant and semi-current PPPs. This robustness check points to a different explanation for the increasing discrepancy between the constant production PPPs and the current expenditure PPPs after 2000.

2.3.2 The nominal exchange rate as a proxy for relative net export prices

Another explanation for the widening gap between constant and current PPPs relates to how net exports is treated in the construction of current expenditure PPPs. The contribution from net exports to the total PPP is based on the assumption that market exchange rates can be used to value net exports (Eurostat and OECD, 2012, Section 12.39). To be precise, the contribution from net exports (NX) is calculated as

$$1/2 (s_{jt}^{NX} + s_{kt}^{NX}) \ln(PPP_{jkt}^{NX}) \quad (2.3)$$

where $s^{NX} = \frac{P^X X - P^M M}{PY}$ represents the share of net exports in GDP measured in current prices and where the official exchange rate is used to proxy relative net export prices PPP_{jkt}^{NX} . Using exchange rates to proxy relative net export prices is a strong assumption since the construction of a net export price index does not have the consistency in aggregation property.⁸ When import and export prices have different growth rates, the aggregate net export price index may show little correspondence with how terms of trade develop. The reason is that net exports can take upon both positive and negative values. As pointed out by Diewert (2005, p. 12): “...normal index number theory fails spectacularly as a value aggregate approaches zero”. It is only in the extreme case where relative import and export prices between countries both follow the exchange rate that the procedure used to create official PPPs is valid. To illustrate, consider the Törnqvist PPP index for net exports between countries j and k

$$\ln(PPP_{jkt}^{NX}) = 1/2 (\tilde{s}_{jt}^X + \tilde{s}_{kt}^X) \ln(PPP_{jkt}^X) - 1/2 (\tilde{s}_{jt}^M + \tilde{s}_{kt}^M) \ln(PPP_{jkt}^M), \quad (2.4)$$

where the superscripts X and M refer to exports and imports, respectively, and where \tilde{s}^X and \tilde{s}^M represents the export and import share of net exports measured in current prices, i.e., $\tilde{s}^X = \frac{P^X X}{P^X X - P^M M}$ and $\tilde{s}^M = \frac{P^M M}{P^X X - P^M M}$, respectively. To calculate the total impact from net export prices to PPP_{jkt} for GDP, the index (Equation 2.4) must be weighted with the mean share of net exports in GDP between the two countries. Accordingly, inserting Equation 2.4 into Equation 2.3 yields

$$\begin{aligned} 1/2 (s_{jt}^{NX} + s_{kt}^{NX}) \ln(PPP_{jkt}^{NX}) &= 1/4 (s_{jt}^{NX} + s_{kt}^{NX}) (\tilde{s}_{jt}^X + \tilde{s}_{kt}^X) \ln(PPP_{jkt}^X) \\ &\quad - 1/4 (s_{jt}^{NX} + s_{kt}^{NX}) (\tilde{s}_{jt}^M + \tilde{s}_{kt}^M) \ln(PPP_{jkt}^M). \end{aligned} \quad (2.5)$$

⁸ An index is *consistent in aggregation* when “the index for some aggregate has the same value whether it is calculated directly in a single operation, without distinguishing its components, or it is calculated in two or more steps by first calculating separate indices, or sub-indices, for its components, or sub-components, and then aggregating them, the same formula being used at each step” (OECD, 2007b, p. 136).

In contrast to the seminal result from Diewert (1978), where it was shown that the Törnqvist index is approximately consistent in aggregation, the two-step procedure in Equation 2.5 is not consistent in aggregation. While the value aggregates in Diewert (1978) were of the same sign, the net export figure in Equation 2.5 can take on both positive and negative values, possibly yielding very different results compared with a one-step procedure, see also ILO et al. (2009, p. 468). Ideally, if data on relative export and import prices between countries are available, the contribution from net exports should be calculated as the separate sum of contributions from exports and imports

$$1/2 (s_{jt}^X + s_{kt}^X) \ln(PPP_{jkt}^X) - 1/2 (s_{jt}^M + s_{kt}^M) \ln(PPP_{jkt}^M), \quad (2.6)$$

where s^X and s^M represents the export and import shares of GDP measured in current prices, i.e., $s^X = \frac{P^X X}{PY}$ and $s^M = \frac{P^M M}{PY}$, respectively. There is no particular reason why the calculation from the one-step procedure (Equation 2.6) should equal the two-step aggregation procedure (Equation 2.5) since the weights in the two expressions can be very different. Only if $PPP_{jkt}^X = PPP_{jkt}^M$ will the two methods be equal irrespective of the weights. If the exchange rate perfectly reflects the relative price of both exports and imports, the procedure used by Eurostat and OECD to aggregate PPPs is therefore valid. However, if the exchange rate does not perfectly reflect the relative price of both exports and imports, the two methods can yield very different results. To illustrate, compare the export weights $1/2 (s_{jt}^X + s_{kt}^X)$ with the weights from the two-step procedure $1/4 (s_{jt}^{NX} + s_{kt}^{NX}) (\tilde{s}_{jt}^X + \tilde{s}_{kt}^X)$ for Norway and the USA. The export share s^X in 2010 was 0.41 in Norway and 0.12 in the USA, which yields an average export share equal to 0.26. The export share out of net exports \tilde{s}^X in Norway was 3.39 and it was -3.55 in the USA, reflecting a negative trade balance. Since one country is running a trade surplus and the other country is running a trade deficit, the mean of these export shares can be close to zero. In this case the mean was -0.08. To get the overall weight, this number must be multiplied with the mean net export share of total GDP. In Norway the net export share was 0.12 and in the USA it was -0.03, which yields a mean equal to 0.05. The aggregate product of mean net export shares and mean export shares then equals -0.003. As a result, the export price growth in the two-step approach in Equation 2.5 is given negligible (and negative) weight compared with the one-step approach in Equation 2.6.

Figure 2.2 compares the results from applying Equation 2.5 and Equation 2.6 when relative export and import price indices are used as proxies for $PPP_{NOR,USA}^X$ and $PPP_{NOR,USA}^M$. The two-step aggregation procedure (Equation 2.5) yields by all practical means no contribution to aggregate PPP after 1999. In contrast, the one-step aggregation (Equation 2.6) shows that net exports contributes to a 16 per cent higher PPP

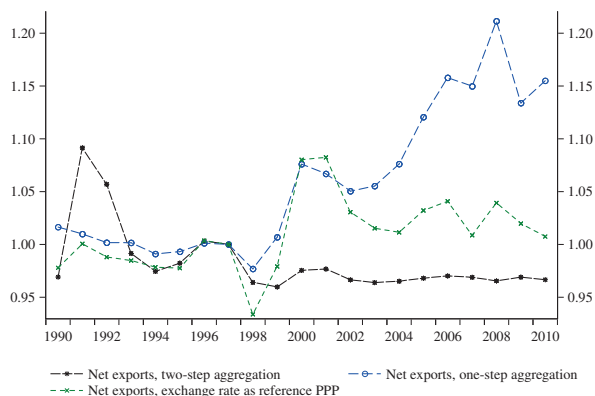


FIGURE 2.2: Contribution to changes in bilateral PPPs between Norway and USA. Source: OECD, author's calculations. Relative export and import price indices between the USA and Norway are used in Equation 2.5 and Equation 2.6 to calculate *Net exports, two-step aggregation* and *Net exports, one-step aggregation* respectively. The series *Net exports, exchange rate as reference PPP* is calculated as $1/2(s_{NOR}^{NX} + s_{USA}^{NX}) \ln(EX_{NOR,USA})$, where EX is the official exchange rate between Norway and USA. All series are normalised to unity in 1997.

in 2010 compared with the level in 1997. For the sake of comparison, the semi-current production PPP for all industries given in Figure 2.1 was 24 per cent higher than the official current PPP published by OECD in 2010. Figure 2.2 also shows the contribution to changes in PPPs when using the official exchange rate as a reference PPP for net exports (Equation 2.3). The volatility of the series between 1997 and 2002 reflects the large changes in Norway's net export share during this time span. In 2010 the level was on par with the value in 1997, indicating that using the exchange rate as reference PPP has not contributed to the aggregate PPP between Norway and USA between 1997 and 2010. The relative price indices for exports and imports might be poor proxies for the development of relative export and import prices (due to the tableau effect). Nevertheless, since index theory fails when value aggregates approaches zero, the results from Figure 2.2 point to the aggregation of net exports as a potential important cause underlying the widening gap between current and constant PPPs.

2.3.3 Is the first premise of the Norwegian productivity puzzle real?

As noted in the introduction, the first premise of the Norwegian productivity puzzle is the high measured level of productivity in Norway. Several issues treated above have shed new light on this premise. It has been shown that how net exports are treated by Eurostat and OECD in the calculation of overall PPPs can be the cause of the

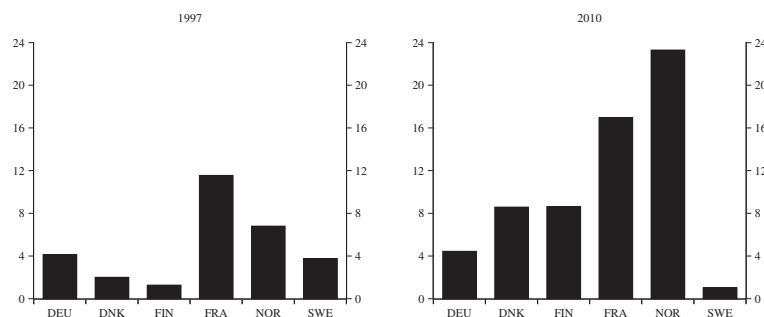


FIGURE 2.3: Difference between constant production PPPs and current expenditure PPPs in 1997 and 2010, per cent. Sources: OECD and EU KLEMS, author's calculations. The constant production PPPs are from Timmer et al. (2006) and aggregated over all industries except petroleum and computers. PPPs are measured in local currency per USD at basic prices, i.e., USA=1. The current expenditure PPP from OECD is converted to basic prices by multiplying with the relative ratio of GDP measured at basic and purchasers' prices between Norway and USA.

widening gap between constant production PPPs and current expenditure PPPs after 1998. As a result, using current expenditure PPPs instead of production PPPs can lead to significant overestimation of the level of productivity, as illustrated in Figure 2.3.⁹ It shows the ratio of expenditure PPPs to production PPPs across countries in 1997 and 2010. In the basis year 1997 the difference is positive for all countries, indicating that productivity is overrated when using the PPPs calculated from the expenditure side. The difference is most pronounced in France at 11.6 per cent and for Norway the difference is 6.8 per cent. For all countries but Sweden, the difference between the current expenditure PPP in 2010 and the constant production PPP in 2010 has increased, in particular for Norway. This general increase across most countries should be viewed in conjunction with how hedonic regressions are widely used by the U.S. Bureau of Economic Analysis to control for quality changes. In the specific case of Norway, however, the increase has been particularly large. As a result, using constant production PPPs from Timmer et al. (2006) to evaluate productivity in 2010 yields a 23.3 per cent lower level of productivity in Norway compared with using current expenditure PPPs. The first premise of the Norwegian productivity puzzle can thus be an artifact of the choice of PPPs and the strong assumption that exchange rates are a good proxy for relative net export prices.

Figure 2.4 shows levels of labour productivity across countries, measured as value added per hour worked in all industries except petroleum and computers, converted from domestic currency to US dollars using constant production PPPs from Timmer et al. (2006). In the 1970s, the level of labour productivity in Norway was 28 per cent below

⁹Recently, Warner et al. (2014) shows how the use of PPPs with different benchmark years impacts the level and trend of global inequality.

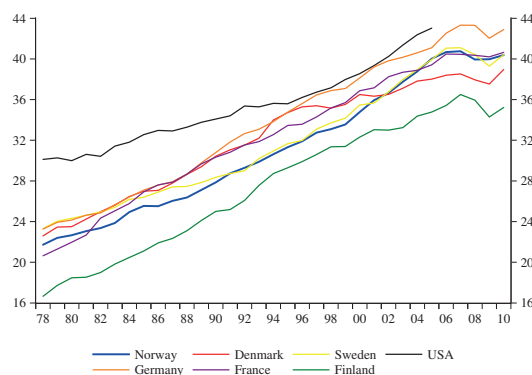


FIGURE 2.4: Value added per hour worked. Sources: OECD and EU KLEMS, author's calculations. Measured in basic prices and USD using constant production PPPs from Timmer et al. (2006). All industries except petroleum and computers.

the level in the USA, 7 per cent below the level in Sweden and 4 per cent below the level in Denmark, but 30 per cent higher than in Finland. During the 1980s the growth in labour productivity was lower than in most of the other countries, but in the mid 1990s, growth picked up. By 2005, the level of labour productivity in Norway was at par with the levels in Sweden and France, and the distance to the level in the USA had shrunk to 7 per cent. In contrast to the first premise of the Norwegian productivity puzzle, Figure 2.4 illustrates that Norway is not particularly productive compared with the USA, Germany, Sweden and France when measured by production PPPs, although performance has been good from the mid 1990s.

2.4 Comparing productivity growth across countries

In the previous section it was shown that when using constant production PPPs from Timmer et al. (2006) the level of productivity in Norway is on par with the level in Sweden and France and somewhat lower than in the USA and Germany. Nevertheless, except for Sweden, trend productivity growth was somewhat higher from the mid 1990s. In light of moderate R&D spending, is the development in Norway still a puzzle? In this section, I answer this question by estimating a model suitable for identifying the role of technology transfer, R&D capital and human capital for productivity growth across countries.

2.4.1 Econometric specification

In this section I outline the basis for the econometric model. Value added Y_{ijt} in industry i in country j at time t is produced with labour L_{ijt} and capital K_{ijt} according to the production technology

$$Y_{ijt} = A_{ijt} F_{ij}(L_{ijt}, K_{ijt}), \quad (2.7)$$

where the function $F_{ij}(\cdot)$ is assumed to be homogenous of degree one and to exhibit diminishing marginal return to each factor. A_{ijt} is an index for total factor productivity (TFP) and is allowed to vary across industries, countries and time. The country with the highest level of TFP in industry i at time t is defined as the frontier country, denoted by A_{iFt} .

The starting point of the analysis is the literature connecting the index for TFP (A_{ijt}) with R&D and the level of technology at the frontier. I employ a model that is a combination of the ones used by Griffith et al. (2004), Cameron et al. (2005) and Coe et al. (2009). Griffith et al. (2004) and Cameron et al. (2005) modelled TFP growth as a function of the distance to the technology frontier and R&D intensity, among other things. In contrast to Griffith et al. (2004), who focused on the rate of change in TFP, Coe et al. (2009) analysed the level of TFP. The level was modelled as a function of both the domestic R&D capital stock and the foreign R&D capital stock. The starting point of the model used in the current chapter is a specification where TFP in levels (log transformed) in industry i of country j is a function of both the TFP level in the frontier industry A_{iFt} , the R&D capital stock R_{ijt} , and human capital S_{ijt} , proxied by high skilled workers' share in total hours worked

$$\ln A_{ijt} = c_{ij} + \eta_{ijt} \ln R_{ijt} + \gamma_{ijt} \ln A_{iFt} + \phi S_{ijt}. \quad (2.8)$$

Both elasticities of TFP with respect to TFP in the frontier country (γ_{ijt}) and R&D (η_{ijt}) are time varying. A constant elasticity of TFP with respect to R&D is "not consistent with any reasonable optimal R&D behaviour" if there are large differences in the R&D intensity (Griliches, 1998, p. 221). A more reasonable assumption is to let the real rate of return $\tilde{\eta} = \partial Y_{ijt} / \partial R_{ijt}$ be common across industries. Also, the extent to which the level of TFP depends on the frontier level of TFP is time dependant. It is reasonable to expect the potential for technology transfer to be greater when the distance to the frontier is large. To be specific, γ_{ijt} should go towards zero when the productivity level goes towards the productivity level in the frontier. One functional form that satisfies this criterion is $\gamma_{ijt} = \tilde{\gamma} \ln(A_{iFt-1}/A_{ijt-1})$. Inserting this relationship and the relationship that the elasticity of R&D equals the product of the real return of R&D and the R&D

intensity ($\eta_{ijt} = \tilde{\eta} R_{ijt}/Y_{ijt}$) back into Equation 2.8 yields the equilibrium relationship

$$\ln A_{ijt} = c_{ij} + \tilde{\eta} \ln \tilde{R}_{ijt} + \tilde{\gamma} \ln \tilde{A}_{iFt} + \phi S_{ijt}. \quad (2.9)$$

where I have defined the auxiliary variables

$$\tilde{R}_t = e^{(R_{ijt}/Y_{ijt}) \ln R_{ijt}} \quad \text{and} \quad \tilde{A}_{iFt} = e^{\ln(A_{iFt-1}/A_{ijt-1}) \ln A_{iFt}}.$$

The model will be estimated using a panel of annual data for seven OECD countries spanning 1978 - 2007. To analyse if productivity growth in Norway represents a puzzle I compare the unexplained level of productivity growth in Norway between 1995 and 2005 with the unexplained productivity growth in Sweden, Denmark, Finland, France, Germany and the USA.

2.4.2 Data description

Data are taken from the OECD STAN database, the EU KLEMS database and Statistics Norway. Data on value added, hours worked, labour compensation, the capital stock, etc. are for Norway, Sweden, Denmark, Finland, Germany and France taken from the OECD STAN database. The only exception is the construction and the Wholesale and retail trade industry in Norway, where data are taken from Statistics Norway. For USA, the National Accounts data by industry are taken from the EU KLEMS database where data from both the 2008 and 2009 release have been used, see O'Mahony and Timmer (2009). Data sources are thus consistent within these countries, but vary between USA and the other countries. The exception is data on hours worked and labour compensation for different educational groups. These data are taken from EU KLEMS for all countries but Norway, where data are taken from Statistics Norway. There are some discrepancies between the industry classification for educational data and the ISIC Rev. 4 classification. For example, the Norwegian data exclude the *Transport via pipelines* industry from the aggregate transportation industry. Also, companies and organisations that are labeled as private enterprises within the *Public administration and defence; education; human health and social work activities* (D84t88) are a part of the *Other services* industry in the Norwegian data. Also, data for Sweden and Germany have been extrapolated backwards using the growth rates from the EU KLEMS database. Purchasing power parities for gross fixed capital formation are taken from OECD and Eurostat (2008). EU KLEMS data and OECD data for France have been mapped from the ISIC Rev. 3 classification to ISIC Rev. 4 classification using the approximate 2-digit mapping provided in The OECD Compendium of Productivity Indicators 2013 (OECD,

2013, Annex D), see also the appendix, Section A.4. Data from EU KLEMS (USA) and OECD ISIC Rev. 3 (FRA), such as value added and gross production, have been extrapolated with growth rates from the OECD STAN ISIC Rev. 4 database if the variables were available. Population and employment data are taken from the Labour force survey (LFS). For Germany data have been extrapolated assuming a constant level between 1990 and 1991 and using the growth rates from LFS prior to 1990 to extend the series backwards in time.

R&D investments are taken from the OECD database ISIC Rev 4. For many countries, R&D surveys have not been completed every year. Log linear interpolation has been used to impute missing observations. Nominal R&D expenditure has been extrapolated backwards using the growth rate from both OECD ISIC Rev. 3 data and ISIC Rev.2 data, see the appendix, Section A.3. For Denmark and Sweden the levels from the ISIC Rev. 2 data have been used. The R&D deflator is the output price index from the R&D sector (D72) if it was available, otherwise the R&D deflator from the Main Science and Technology Indicators by OECD is used. If the output price index from the R&D sector was available it has been extrapolated using the growth rate from the R&D deflator in the Main Science and Technology Indicators. To get a measure of R&D capital in industry i of country j (R_{ijt}) I apply the Perpetual Inventory Method

$$R_{ijt} = (1 - \delta)R_{ijt-1} + I_{ijt}, \quad (2.10)$$

where I_{ijt} is real R&D investments constructed from nominal R&D investments and the R&D deflator using the product rule¹⁰ and where I have used the depreciation rate $\delta = 0.15$ and the initial condition $R_{ij0} = I_{ij0}/(\delta + 0.05)$ by following Hollanders and ter Weel (2002, p. 588). Table 2.1 shows the median R&D intensity, defined as the ratio of real R&D investments to value added (I_{ijt}/Y_{ijt}), between 2005 and 2010 across industries and countries. The R&D intensity in Manufacturing in Norway is roughly half the mean intensity in the other countries. A low level of R&D intensity is consistent with the low level of productivity growth in manufacturing. Overall, the R&D intensity in Manufacturing is much higher than in the other industries. The R&D intensity in Information and communication is also relatively high in all countries. In the Wholesale and retail trade industry however, it is below unity in all countries. The puzzling productivity growth in this industry for Norway can therefore not be explained by the level of R&D investments. The total R&D intensity in Norway, calculated as a weighted average of the industry specific intensities using value added shares as weights, is 2.0 per cent. All of the other countries have a higher total R&D intensity, where the highest is in Finland and Sweden at 4.6 per cent. The low overall R&D intensity in

¹⁰The product rule refers to the identity of a value ratio being equal to a price ratio times a quantity ratio, see Frisch (1930).

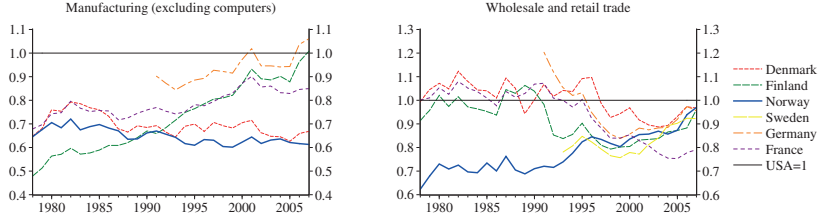


FIGURE 2.5: Comparing TFP levels across countries. Sources: OECD and EU KLEMS, author's calculations. The figure illustrates the TFP levels of industry i in country j relative to industry i in the USA, i.e., (A_{ij}/A_{iUSA}) .

Norway is thus partly a result of a low R&D intensity in manufacturing in combination with manufacturing accounting for a lower share of total value added in Norway than in the other countries.

To get a measure for the distance to the frontier I apply the spatial productivity index suggested by Caves et al. (1982)

$$\ln A_{ij} - \overline{\ln A_i} = (\ln Y_{ij} - \overline{\ln Y_i}) - 1/2(s_{ij}^K + \overline{s_i^K})(\ln K_{ij} - \overline{\ln K_i}) - 1/2(s_{ij}^L + \overline{s_i^L})(\ln L_{ij} - \overline{\ln L_i}), \quad (2.11)$$

where Y_{ij} , K_{ij} , L_{ij} and s_{ij} represent value added, the net capital stock, hours worked and the factor shares respectively. $\overline{\ln Y_i}$, $\overline{\ln K_i}$ and $\overline{\ln L_i}$ are the geometric means of value added, the net capital stock and hours worked across $n = 7$ countries, e.g., $\overline{\ln Y_i} = \frac{1}{n} \sum_{j=1}^n \ln Y_{ij}$, and $\overline{s_i}$ is the arithmetic mean of the respective factor share across countries, i.e., $\overline{s_i} = \frac{1}{n} \sum_{j=1}^n s_{ij}$. The frontier A_{iF} is defined as the country with the highest index value $(\ln A_{ij} - \overline{\ln A_i})$ in any given time period. An industry's distance to the frontier is measured by $(\ln A_{ij} - \overline{\ln A_i}) - (\ln A_{iF} - \overline{\ln A_i}) = (\ln A_{ij} - \ln A_{iF})$ in a given base year.

In Figure 2.5, the development of industry productivity is shown relative to USA (A_{ijt}/A_{iUSAt}) between 1978 and 2007 for Manufacturing and Wholesale and retail trade. In Manufacturing, the USA was the frontier country for most of the time period. All countries but Denmark and Norway show a tendency for convergence. The productivity level in Norway has been between 60 and 70 per cent below the productivity level in the USA during this time period. In contrast, Finland has shown a great surge in relative productivity growth, a development that should be viewed in relation to the development of the mobile phone producer Nokia during this time period. The development in Wholesale and retail trade differs from Manufacturing in several respects. While the

TABLE 2.1: Descriptive statistics

	NOR	USA	DNK	SWE	FRA	FIN	DEU
<i>TFP as Proportion of Frontier TFP (per cent)^a</i>							
Agriculture, forestry and fishing	51.5	100	79.5	93.2	55.7	36.3	85.8
Manufacturing	47.2	92.4	48.9	99.3	67.2	98.5	79.6
Construction	78.5	64.9	71.6	63.5	71.0	100	69.0
Wholesale and retail trade	95.4	100	89.9	88.0	76.8	94.4	96.1
Transportation and storage	51.8	100	64.5	61.8	78.2	83.8	69.1
Information and communication	98.3	100	62.2	94.6	n/a	60.1	71.6
Financial and insurance activities	61.2	88.1	100	86.1	71.3	78.3	37.2
Total	69.6	92.1	72.5	88.5	64.3	87.9	76.8
<i>R&D intensity^b</i>							
Agriculture, forestry and fishing	1.7	n/a	0.3	n/a	0.3	0.0	0.5
Manufacturing	4.7	10.4	9.9	12.5	7.0	10.2	7.7
Construction	0.5	0.2	0.0	0.2	0.1	0.3	0.1
Wholesale and retail trade	0.3	0.2	0.6	0.0	0.5	0.4	0.1
Transportation and storage	0.1	0.0	0.2	n/a	0.1	0.2	0.1
Information and communication	4.7	5.9	7.1	n/a	3.0	4.5	2.0
Financial and insurance activities	1.2	0.1	2.0	0.5	0.2	1.5	0.2
Total	2.0	3.7	3.0	4.6	2.3	4.6	3.5
<i>Share of high skilled in total hours worked^c</i>							
Agriculture, forestry and fishing	54.5	n/a	45.8	69.4	70.3	73.7	57.7
Manufacturing	61.3	n/a	67.5	79.7	76.4	79.1	73.5
Construction	61.4	n/a	68.7	77.8	69.5	75.5	70.9
Wholesale and retail trade	43.8	n/a	66.0	78.7	80.7	77.2	66.4
Transportation and storage	51.6	n/a	61.2	82.6	76.9	70.1	66.4
Information and communication	72.3	n/a	27.9	n/a	21.8	23.0	17.7
Financial and insurance activities	54.5	n/a	89.3	95.9	95.0	84.0	89.0
Total	55.1	n/a	63.5	74.0	74.1	72.8	67.7

Sources: OECD, Statistics Norway and EU KLEMS, author's calculations. Sample: 2005 – 2010, medians.

^a Defined as $100 \times (A_{ij}/A_{iF})$, where A_{ij} is TFP in industry i in country j and where A_{iF} is TFP in the frontier country. (A_{ij}/A_{iF}) is calculated using the spatial productivity index in Caves et al. (1982), see Equation 2.11. *Total* is calculated as a weighted average across industries where the weights are value added shares.

^b Calculated as the ratio of real R&D investments to real value added. *Total* is calculated as a weighted average across industries where the weights are value added shares.

^c For Norway, labour with either vocational or tertiary education are defined as high skilled. For the remaining countries high skilled are defined as DNK: Long to short-cycle higher education and vocational education and training, SWE: Postgraduates, undergraduates, higher and intermediate vocational, FRA: University graduates, higher education below degree, low intermediate and vocational education, FIN: Tertiary schooling (or parts thereof), upper secondary level with or without matriculation, DEU: University graduates and intermediate education, see Timmer et al. (2010, Table 3A.4, includes both high and medium skilled). *Total* is calculated as a weighted average across industries where the weights are shares in total hours worked.

USA was by far the technology leader in Manufacturing in the 1980s, almost all countries were at the level of USA in Wholesale and retail trade. The exception is Norway. In 1978 the relative productivity level was 60 per cent compared with the USA. At that time there were not many chain stores and not many shopping malls in Norway.¹¹ From a state of great inefficiency, Norway has had surge in productivity growth, even when compared to the USA which growth were much higher than in Europe during the 1990s. In 2007 the productivity in Norway is at level of Sweden, Denmark, and Germany, but still about 3 per cent lower than in the USA. Table 2.1 shows productivity levels across industries. There are large variations in productivity levels across countries. Except for the Wholesale and retail trade and Information and communication industries, the technology level in Norway is about 45 to 65 per cent of the technology leader. Interestingly, with the exception of these two industries, the other countries are ahead of Norway in most of the other industries. One exception is the low level of productivity in Germany in Financial and insurance activities.

Table 2.1 also shows the share of high skilled labour in total hours worked. Due to different education systems the definition of high and low skilled varies across countries. In Norway, labour with no formal qualifications, primary education, secondary school (excluding vocational education) or unknown are defined as low skilled. Labour with either vocational or tertiary education are defined as high skilled. For the remaining countries high skilled are defined by: long to short-cycle higher education and vocational education and training in Denmark, postgraduates, undergraduates, higher and intermediate vocational in Sweden, university graduates, higher education below degree, low intermediate and vocational education in France, tertiary schooling (or parts thereof), upper secondary level with or without matriculation in Finland and university graduates and intermediate education in Germany (Timmer et al., 2010, Table 3A.4, includes both high and medium skilled). The difference in educational systems and the different definitions of high skilled means that the high skill share in total hours worked is not directly comparable across countries. Equation 2.9 is therefore estimated both with and without the human capital variable. Nevertheless, there are important differences across countries. The largest share of high skilled can be found in the Information and communication industry in Norway. In contrast, in all other countries, this industry has the lowest share of high skilled. Also, the high skill share in both Wholesale and retail trade and in Financial and insurance activities is lower in Norway than in the other countries. In all countries but Norway, the largest high skill share can be found in the Financial and insurance activities.

¹¹The first chain store *Jernia* was established around 1960 and what was referred to as the first shopping mall *Eiksmarka senter* was established in 1953. But the surge in shopping malls began first in the late 1980s and in the 1990s (Rasmussen and Reidarson, 2007).

TABLE 2.2: Panel unit root tests

	TFP	R&D	TFP–frontier	Skill intensity
Levin et al. (2002) ^a	2.24 (0.99)	0.81 (0.79)	-15.38** (0.00)	1.78 (0.96)
Breitung (2000) ^b	6.58 (1.00)	1.96 (0.97)	0.46 (0.68)	1.76 (0.96)
Hadri (2000) ^c	17.95** (0.00)	14.07** (0.00)	11.23** (0.00)	14.22** (0.00)

Sample: 1977 – 2008, 7 countries, 6 industries. The 10 and 5 per cent significance levels are marked with * and **, respectively. p -values in parenthesis. The TFP variable is defined by $\ln A_{ijt}$. The R&D and TFP–frontier variables are defined by the auxiliary variables $\tilde{R}_t = e^{(R_{ijt}/Y_{ijt}) \ln R_{ijt}}$ and $\tilde{A}_{iFt} = e^{\ln(A_{iFt-1}/A_{ijt-1}) \ln A_{iFt}}$, where R , Y and A represent R&D investments, value added and TFP, respectively, and where the index F denotes the frontier country with the highest level of TFP. Skill intensity is defined by high skilled workers' share in total hours worked. Countries included: USA, Germany, France, Finland, Sweden, Denmark and Norway. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities.

^a Null hypothesis: Unit root.

^b Null hypothesis: Stationarity.

2.4.3 Results

Before estimating the long run relationship in Equation 2.9, the variables are tested for unit roots and cointegration. Three different types of unit root tests are conducted, based on the methods in Levin et al. (2002), Breitung (2000) and Hadri (2000), see Table 2.2. All variables shows sign of unit roots. In the first two tests the null hypothesis is that the series contain a unit root, whereas in Hadri (2000) the null hypothesis is that the series are stationary. Except for the test of the frontier variable $\ln \tilde{A}_{iFt}$ using the method in Levin et al. (2002), none of the tests reject the null hypothesis of a unit root. Both the Breitung (2000) test and the Hadri (2000) test point to a unit root also in the frontier series $\ln \tilde{A}_{iFt}$.

Tests for cointegration among the variables (Pedroni, 1999) are based on a pooled sample and by imposing both a deterministic intercept and trend, see Table 2.3. These tests indicate that the series are cointegrated. The evidence is weakest for the panel ρ -statistic, where the null hypothesis of no cointegration cannot be rejected at the 10 per cent significance level. However, the three other tests all reject the null hypothesis of no cointegration at least at the 10 per cent significance level, with the only exception

TABLE 2.3: Panel cointegration tests

	Panel v	Panel ρ	PP	ADF
TFP, R&D	13.48**	0.89	-0.33	-1.45*
TFP, R&D, TFP–frontier	12.81**	1.26	-2.26**	-3.79**
TFP, R&D, TFP–frontier, Skill intensity	2.11**	2.01	-2.67**	-4.07**

Sample: 1977 – 2008, 7 countries, 6 industries. Pedroni (1999) cointegration tests, assuming both a deterministic intercept and trend. The 10 and 5 per cent significance levels are marked with * and **, respectively. The null hypothesis of no cointegration is rejected if the test statistic is significant. The TFP variable is defined by $\ln A_{ijt}$. The R&D and TFP–frontier variables are defined by the log of the auxiliary variables $\tilde{R}_t = e^{(R_{ijt}/Y_{ijt}) \ln R_{ijt}}$ and $\tilde{A}_{iFt} = e^{\ln(A_{iFt-1}/A_{ijt-1}) \ln A_{iFt}}$, where R , Y and A represent R&D investments, value added and TFP, respectively, and where the index F denotes the frontier country with the highest level of TFP. Skill intensity is defined by high skilled workers' share in total hours worked. Countries included: USA, Germany, France, Finland, Sweden, Denmark and Norway. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities.

for the PP test between the TFP and the R&D variable. Interestingly, the evidence is stronger in the specifications that includes the distance to the frontier and the share of high skilled labour (S_{ijt}). These results suggest that a stable long-run relation can be estimated using a pooled estimation technique.

Three different models are estimated and the results are reported in Table 2.4. Dynamic OLS (DOLS) has been used to estimate both models. This estimator was suggested by Saikkonen (1991) and it has been commonly used in the literature, see e.g., Kao et al. (1999) and Coe et al. (2009). In contrast to the standard OLS estimator, the DOLS estimator controls for both serial correlation and endogeneity among the regressors, and in Monte Carlo experiments it also outperforms the Fully Modified OLS estimator, see Kao and Chiang (2000). It is a suitable estimator also when the time series are dependant across industries since the data is demeaned over the cross-section dimension before the augmented cointegrating regression is estimated, see Mark and Sul (2003, p. 668).

Only the R&D variable enter as explanatory variable in Model 1. The estimated return to R&D, estimated to 5 per cent, is significant at the 5 per cent significance level. An estimated return to R&D of 5 per cent is lower than what is found in many other studies. As shown in Hall et al. (2010) there is great variation in estimated returns to R&D, but most studies find rate of returns larger than 10 per cent. One exception is the study by Parisi et al. (2006) who estimate the return of R&D to approximately 4 per cent using

TABLE 2.4: Estimation results

	Model 1	Model 2	Model 3
R&D	0.05** (0.01)	0.05** (0.01)	0.00 (0.01)
TFP–frontier		0.80** (0.14)	0.92** (0.16)
Skill intensity			0.95** (0.09)
Standard error	0.12	0.11	0.09
R^2	0.92	0.94	0.96
Observations	409	384	337
Sample	1977 – 2007	1977 – 2007	1977 – 2007
Estimator	DOLS	DOLS	DOLS

The dependent variable is the natural logarithm of total factor productivity ($\ln A_{ijt}$). The 10 and 5 per cent significance levels are marked with * and **, respectively. Standard errors in parenthesis. Estimation is conducted using Panel Dynamic OLS (DOLS) where leads and lags specifications are based on the AIC criterion. The R&D and TFP–frontier variables are defined by the log of the auxiliary variables $\tilde{R}_t = e^{(R_{ijt}/Y_{ijt}) \ln R_{ijt}}$ and $\tilde{A}_{iFt} = e^{\ln(A_{iFt-1}/A_{ijt-1}) \ln A_{iFt}}$, where R , Y and A represent R&D investments, value added and TFP, respectively, and where the index F denotes the frontier country with the highest level of TFP. Skill intensity is defined by high skilled workers' share in total hours worked. Countries included: USA, Germany, France, Finland, Sweden, Denmark and Norway. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities.

Italian data. In Model 2 the impact from the distance to the technological frontier is included and significantly estimated. The inclusion of this variable has negligible effect on the estimated return to R&D. In Model 3 the share of high skilled is also added as an explanatory variable. It is estimated significantly at the 5 per cent level. Interestingly, when the share of high skilled is added as an explanatory variable, the return to R&D, which was estimated significantly at 5 per cent, drops to 0 per cent and is insignificant.

The main purpose of this section is to see if there has been a particular development of productivity in Norway during the period 1995 – 2005. To this end, I use the framework developed above and analyse the difference between actual TFP growth and the TFP

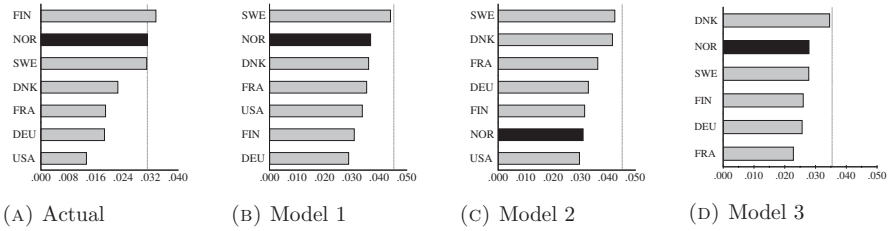


FIGURE 2.6: Actual and unexplained TFP growth. Sample: 1995 – 2005. Median growth rate. Actual TFP growth for country j is calculated as the weighted average across industries i of actual TFP growth ($\Delta \ln A_{ijt}$), i.e., $\sum_i s_{ijt} \Delta \ln A_{ijt}$, where the weights s_{ijt} are value added shares measured in current prices. Unexplained TFP growth in country j is calculated as the weighted average across industries i of the difference between actual and model predicted TFP growth ($\Delta \ln A_{ijt}^M$) in absolute terms, i.e., $\sum_i s_{ijt} |\Delta \ln A_{ijt} - \Delta \ln A_{ijt}^M|$. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities. The vertical line is 0.9 standard deviations above the mean across countries in each panel.

growth implied by Models 1 – 3 in Figure 2.6. For all countries are Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities included, but only for only for Norway, Denmark, France and Germany is the Manufacturing industry included in the sample. Actual TFP growth for country j is calculated as the weighted average across industries i of actual ($\Delta \ln A_{ijt}$) TFP growth, i.e., $\sum_i s_{ijt} \Delta \ln A_{ijt}$, where the weights s_{ijt} are value added shares measured in current prices. The unexplained growth in country j is calculated as the weighted average across industries i of the difference between actual and model predicted ($\Delta \ln A_{ijt}^M$) TFP growth in absolute terms, i.e., $\sum_i s_{ijt} |\Delta \ln A_{ijt} - \Delta \ln A_{ijt}^M|$. Note that the unexplained TFP growth in Models 1 – 3 in Figure 2.6 does not show the error of how the models would predict aggregate TFP growth in each country. Such a measure would yield smaller errors since a negative prediction error in one industry would be offset by a positive prediction error in another industry.

Figure 2.6a shows the median growth rate in actual TFP. Growth in TFP has been much higher in the Nordic countries between 1995 and 2005 compared with the growth in USA, Germany and France. In Norway the median growth rate was 3.1 per cent and 0.9 standard deviations above the mean, represented by the vertical line.

A productivity puzzle can loosely be defined as a high level of actual TFP growth compared with a low level of the determinants of TFP, such as R&D. If a productivity puzzle exists, one would expect the unexplained level of TFP to be higher in Norway when taking the determinants of TFP into account. To analyse if there has been a productivity puzzle in Norway, I compare the level of unexplained TFP in Norway when using Models 1 – 3. If a puzzle exists, one would expect the unexplained level of TFP

in Norway being further away from the mean compared with the distance to the mean of actual TFP (0.9 standard deviations). As shown in Figure 2.6b – Figure 2.6d, for all models, the unexplained level of TFP in Norway is less than 0.9 standard deviations from the mean. In Model 1, when taking only R&D into account, the unexplained level of TFP in Norway is 0.3 standard deviations above the mean. In Model 2 and 3 the distance to the mean is -0.8 and 0.1 standard deviations, respectively. In other words, when taking the standard determinants of TFP into account, productivity in Norway is *less* puzzling than what the relatively high growth rate in actual TFP could indicate. Based on these results there is no reason to claim that the development of total factor productivity in Norway between 1995 and 2005 represents a puzzle.

2.5 Conclusions

The Norwegian productivity puzzle is rooted in the seemingly contradictory “facts” that Norway is one of the most productive OECD countries, that Norway has experienced high growth in productivity and that the level of R&D investments has been low. The aim of this chapter has been twofold. The first was to analyse if productivity in Norway really has been as high as reported statistics suggest. I have shown that using PPPs from the expenditure side can grossly overestimate productivity in Norway, mainly because it is assumed that relative net export prices can be proxied by the market exchange rate in the calculation of expenditure PPPs. Since price indices fail when value aggregates, such as net exports, are close to zero, small deviations between the terms of trade and the market exchange rate can yield a large bias in the contribution from export prices and import prices to the overall PPP. It was shown that using terms of trade instead of market exchange rate can account for most of the gap between current expenditure and constant production PPPs. As a result, using expenditure PPPs instead of production PPPs overrates productivity in Norway by 23.3 per cent compared with the USA in 2010. When measured using the production PPPs from Timmer et al. (2006), Norway is not particularly productive compared with either the USA, Germany, Sweden or France. The exceptionally high productivity level in Norway, which was the premise of the Norwegian productivity puzzle, can thus be an artifact of the strong assumption that exchange rates are a good proxy for relative net export prices and the sizable price increase in statistical discrepancies.

The second aim of the chapter was to analyse the relatively high growth in productivity beginning in the mid 1990s. Using an empirical model that took the level of human capital, R&D capital stock and the distance to the technological frontier into account, it was shown that unexplained productivity growth has not been significantly higher

in Norway compared with other countries. In contrast to what a productivity puzzle implies, the unexplained growth in TFP when taking R&D, distance to the technological frontier and human capital into account, is less pronounced in Norway compared with actual growth TFP. Based on these results there is thus no reason to claim that the development of productivity in Norway represents a puzzle.

Chapter 3

Understanding the productivity slowdown: the importance of exit and entry of workers

Abstract: Many OECD countries have experienced a measured slowdown in labor productivity from 2005 and onwards. Norway is no exception in this respect. Most countries use a simple aggregate of hours worked when measuring labour productivity. One way to improve measurement of labour services is to control for worker characteristics. A theoretical rationale for doing so is given by Diewert and Lippe (2010). We generalise previous analyses by allowing for exit and entry by workers when measuring labor services for Norway. We find that the bias from using hours worked compared to a labour index capturing various compositional effects can be substantial and systematic over time. In the case of Norway they explain about a quarter of the productivity slowdown after 2005.

3.1 Introduction

Many OECD countries have experienced a measured slowdown in labor productivity from 2005 and onwards. Norway is no exception in this respect. While the average productivity growth was 2.7 per cent between 2002 and 2005, it dropped markedly after 2005 and reached -1.4 per cent in 2008, see Figure 3.1. This productivity slowdown occurred in tandem with a massive increase in immigration following the 2004 enlargement of the European Union. As Figure 3.1 illustrates, the ratio of net immigration to the total number of employees almost tripled from a level of about 0.6 before 2005 to 1.7 in 2008. Several other European countries have experienced a similar surge in immigration after 2005.

This chapter is written together with Ådne Cappelen and Diana-Cristina Iancu. Thanks to Karen Helene Ulltveit-Moe, Pål Boug and Terje Skjerpen for useful comments. The usual disclaimer applies.

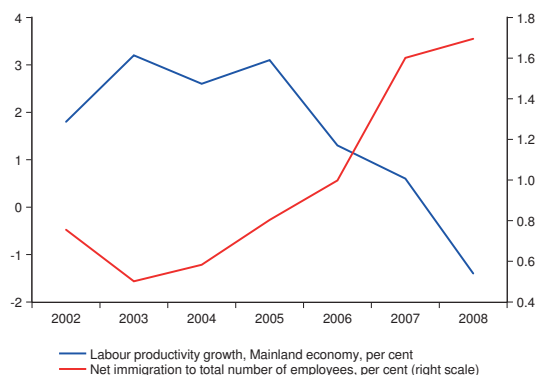


FIGURE 3.1: Labour productivity and immigration. Labour productivity is measured as value added per hour worked in the mainland economy. Net immigration is shown relative to the total number of employees in Norway. Source: Statistics Norway.

The negative correlation between net immigration and productivity growth raises a particular concern with respect to how productivity is measured. Labour productivity growth is defined as the ratio of the index for value added to the index for labour services. It is standard practice to use the change in hours worked as a proxy for the labour services index. However, it is well known that hours worked represents a biased proxy for labour services. The reason is that a worker's contribution to labour services should be weighted by his or her cost to the firm, not the share of hours worked. For example, if there are a large number of low paid immigrants entering the labour market after 2005, and if wages reflect marginal productivity, a measure of labour services based on hours worked would overstate the contribution to labour services and consequently understate the true development in productivity.

The bias between using hours worked and a more theoretically based index for labour services, such as Fisher or Törnqvist, is referred to as the unit value bias. In a more general context, the unit value bias has been discussed extensively in the literature, see e.g., Párnitzky (1974); Timmer (1996); Balk (1998b) and Silver (2010). Diewert and Lippe (2010) summarise many of these findings and analyse the unit value bias more explicitly with respect to the Laspeyres, the Paasche and the Fisher price indices.

To counteract the weaknesses of using hours worked it is common to control for worker characteristics in a two-step procedure: the first step defines groups by worker characteristics and the second step aggregates hours worked across these groups using an index with good theoretical and axiomatic properties such as Törnqvist or Fisher, see e.g., Jorgenson et al. (1987), Jorgenson et al. (2005), Cao et al. (2009) and work based on the EU

KLEMS database such as O'Mahony and Timmer (2009); Timmer et al. (2010). Based on this framework Zoghi (2010) discusses the use of predicted wages in calculating the weighting scheme, which is the current practice at the U.S. Bureau of Labor Statistics. Using data for Norway, Hægeland (1997) calculated labour services using register data and classifications of workers according to education and sex. Nilsen et al. (2011), analysed productivity across manufacturing industries in Norway also using register data and categorised employed persons into 12 subgroups. They added to this literature by using weights based on an estimate of predicted wages associated with individual skill attributes.

The theoretical rationale for the two-step procedure can be found in Párnitzky (1974) and Diewert and Lippe (2010). They show that the unit value bias decreases with increased disaggregation if it is compositional effects between the groups that contribute most to the overall bias. However, if compositional effects within groups are dominant, disaggregation may increase the unit value bias. Note that these theoretical results follow from comparing the change in hours worked relative to indices that require underlying prices and quantities to be defined in both the base and the comparison period, such as the Fisher and Törnqvist indices. But, when applying hours worked to calculate labour services, this proxy is also calculated across those workers that were only present in *either* the comparison period or the base period. The unit value bias should consequently be defined relative to an index that allows for workers entering and exiting the labour market, a property which becomes increasingly important when net immigration surges.

In this chapter, we generalise the results from Párnitzky (1974) and Diewert and Lippe (2010) to allow for workers entering and exiting the labour market. To this end, we build on the theory of Feenstra (1994) who analysed the impact of new product varieties on import prices when the underlying cost function was of constant elasticity of substitution (CES) form. This theoretical framework and some generalisations can also be found in Balk (1999). Using the case of perfect substitutes as a benchmark, we show that the contribution from entering and exiting workers on the unit value bias depends on the unit value of entering and exiting workers relative to the unit value of continuing workers. We also show theoretically that controlling for worker characteristics in the two-step procedure can exacerbate the unit value bias through entering and exiting effects.

Using Norwegian register data spanning the years 2002 to 2008, we empirically decompose the contributions from workers entering and exiting employment and those that are continuously employed. To our knowledge, this is the first study on how entry and exit effects impact aggregate wages, labour services and consequently the measure of productivity. We find that the standard practice of using hours worked overestimates labour services by approximately between 1 to 2 percentage points annually from 2002 to

2008. Correspondingly, wages and productivity are thus underestimated by between 1 to 2 percentage points annually. About half is attributed to a bias among continuing workers and half is attributed to the effect of workers entering and exiting employment. We also find that controlling for the level of education in the two-step procedure exacerbates the unit value bias in most years.

The backdrop of this chapter is the hypothesis that mismeasurement can explain parts of the observed drop in productivity growth in Norway after 2005. On average, productivity grew 2.7 per cent annually in mainland Norway between 2002 and 2005. Between 2006 and 2008 average annual growth reduced to 0.2 per cent, down by about 2.5 percentage points. We show that the bias from using hours worked as a measure for labour services, compared to an index of labour services with desirable properties in line with index theory, increases on average with 0.7 percentage points annually after 2005. Most of this bias is due to an increasing number of entering workers with a relatively low wage rate, a development that must be seen in conjunction with the surge in immigration after 2005. Mismeasurement of productivity can thus explain about a quarter of the measured productivity slowdown after 2005.

The chapter proceeds as follows: Section 3.2 derives theoretically the biases of using unit values and hours worked as indices for wages and labour services, respectively. Section 3.3 presents the data used and Section 3.4 outlines the empirical results. Section 3.5 concludes.

3.2 Biases of standard practice

In this section, we show theoretically the biases of using unit values as the wage index and aggregating hours worked as the quantity index. In particular, these biases will be decomposed into contributions from continuing, entering and exiting workers. In the latter part of this section we also show how the two-step procedure of splitting workers into smaller groups and then using a “proper” index to aggregate can amplify the problem caused by using hours worked as the quantity index.

We start the analysis by introducing some definitions and notation. We let labour costs refer to the nominal *value* of compensation paid to employees for their work and denote labour costs for employee i at time t by V_{it} . Correspondingly, we let W_{it} and H_{it} denote the hourly wage rate and the number of hours worked. Total labour costs at time t are then given by $V_t = \sum_{i \in I_t} V_{it}$, where the set I_t holds all workers with positive working hours at time t . The index number problem is then to decompose aggregate labour costs

into respective price and quantity indices, i.e.,

$$\left(\frac{V_t}{V_{t-1}} \right) = \left(\frac{W_t}{W_{t-1}} \right) \left(\frac{H_t}{H_{t-1}} \right) \quad (3.1)$$

where $\left(\frac{W_t}{W_{t-1}} \right)$ and $\left(\frac{H_t}{H_{t-1}} \right)$ represent indices for wages and labour services, respectively.

There are some workers that were employed at both time periods. We refer to those as *continuing* workers. Workers *entering* employment were employed at time t but not at time $t - 1$. Workers *exiting* employment worked at time $t - 1$ but not at time t . We can thus decompose aggregate growth in labour costs into contributions from continuing, entering and exiting workers. Denote the set of continuing workers by $I = I_{t-1} \cap I_t$.¹² Further, let the set of workers entering employment at time t be denoted by I_t^c and the set of workers exiting employment be denoted by I_{t-1}^c . The total set of workers I_r has then been split into the complement sets I and I_r^c such that $I_r = I \cup I_r^c$ for times $r = t - 1, t$. Given these definitions, the above decomposition can explicitly be written as

$$\begin{aligned} & \underbrace{\left(\frac{\sum_{i \in I_t} V_{it}}{\sum_{i \in I_{t-1}} V_{it-1}} \right)}_{\text{TOTAL}} \\ &= \underbrace{\left(\frac{\sum_{i \in I} V_{it}}{\sum_{i \in I} V_{it-1}} \right)}_{\text{CONTINUING}} \times \underbrace{\left(1 + \frac{\sum_{i \in I_t^c} V_{it}}{\sum_{i \in I} V_{it}} \right)}_{\text{ENTERING}} \times \underbrace{\left(1 + \frac{\sum_{i \in I_{t-1}^c} V_{it-1}}{\sum_{i \in I} V_{it-1}} \right)}_{\text{EXITING}}^{-1}. \quad (3.2) \end{aligned}$$

The growth contribution from entering workers is thus based on the ratio of entering to continuing workers at time t . The higher the ratio of entering to continuing workers, the higher the overall growth in aggregate labour costs. Correspondingly, the contribution from exiting workers depends on the ratio of exiting workers to continuing workers at time $t - 1$. The higher the ratio of exiting to continuing workers, *ceteris paribus*, the lower the overall growth in aggregate labour costs.

Given the above classification, the index number problem of decomposing aggregate labour costs into respective indices for wages and labour services can then be further broken down into separate contributions from continuing, entering and exiting workers. There are thus separate index number problems for the sets of continuing, entering and exiting workers. In this chapter, we will mainly focus on decomposing the change in labour services. Of course, from the product rule in Equation 3.1, any bias in the measure of labour services across either continuing, entering or exiting workers of say

¹²It is assumed that the set of continuing workers is non-empty.

k per cent, is tantamount to a $(1/k)$ per cent bias in the measurement of wages. In the following we first recapitulate the standard practice of using hours worked and then compare it with our definition a “true” index with appropriate theoretical properties.

3.2.1 Decomposing hours worked

The standard measure of change in labour services is obtained by dividing the registered total hours worked at time t by the registered total hours worked at time $t - 1$

$$\left(\frac{\sum_{i \in I_t} H_{it}}{\sum_{i \in I_{t-1}} H_{it-1}} \right), \quad (3.3)$$

where the index i runs across the sets I_t and I_{t-1} of workers with positive working hours at time t and $t - 1$, respectively. As with the decomposition of total labour costs in Equation 3.2, the change in hours worked can be decomposed into contributions from continuing, entering and exiting workers by

$$\begin{aligned} \left(\frac{H_t}{H_{t-1}} \right)_{\text{TOTAL}}^{\text{Hours worked}} &= \underbrace{\left(\frac{\sum_{i \in I} H_{it}}{\sum_{i \in I} H_{it-1}} \right)}_{\text{CONTINUING}} \\ &\times \underbrace{\left(1 + \sum_{i \in I_t^c} H_{it} / \sum_{i \in I} H_{it} \right)}_{\text{ENTERING}} \times \underbrace{\left(1 + \sum_{i \in I_{t-1}^c} H_{it-1} / \sum_{i \in I} H_{it-1} \right)^{-1}}_{\text{EXITING}}. \end{aligned} \quad (3.4)$$

The first term after the equality sign shows the change in hours worked among continuing workers. The second term shows the contribution from entering workers. It is increasing in the ratio of hours worked of entering workers relative to hours worked of continuing workers at time t . Correspondingly, the impact from exiting workers is decreasing in the ratio of hours worked of exiting to continuing workers at time $t - 1$.

3.2.2 Defining the “true” index

In this section we outline our concept of a “true” index both across continuing workers and those entering and exiting employment. We start by recapitulating how a wage index across continuing workers is evaluated and then outline how economic theory can guide us in deriving an index for labour services that takes into account the entry and exit of workers.

Indices calculated across continuing workers are often evaluated on their economic and axiomatic properties. In the axiomatic approach the index should hold a number of desirable properties. For example, the *Identity* axiom states that if wages do not change between time periods neither should the overall index. The *Commensurability* axiom states that the price index should be invariant to changes in the units of measurement. The *Mean value tests* require that the overall wage index lies within the minimum and the maximum wage ratio and that the overall labour services index lies within the minimum and maximum ratio of hours worked. A thorough discussion of these and many more axioms can be found in e.g., The Consumer Price Index Manual (ILO et al., 2004b). It turns out that the Fisher index is the only index number that satisfies all of the 20 axiomatic tests that are discussed in what is labelled the first axiomatic approach. In comparison, the Törnqvist index passes 11 of these tests (ILO et al., 2004b, p. 297). In contrast, in what is labelled the second axiomatic approach, where a price index is defined by two sets of prices and two sets of values (and not quantities), it is the Törnqvist index that passes all of the axiomatic tests.

There are several practical problems with the axiomatic approaches. It is not clear what criteria to use to weight the different tests and how to decide on which of the two axiomatic approaches to use. Also, any given list of axioms can be viewed as arbitrary. Moreover, even if an index fails a particular test, it does not necessarily imply that using this index will result in a large error. Nevertheless, the Fisher and the Törnqvist indices stand out as superior to many of the other indices in the first and second axiomatic approach, respectively. Also, these indices behave similarly as they both use information about value shares in both comparison periods.

Using an economic criterion as a basis for evaluating price indices dates back to Konüs (1939). The purpose of the economic approach is to yield an index that shows the change in the wage cost between two time periods for a given level of production. Interestingly, both the Fisher and the Törnqvist index also score high when assessed by economic criteria. In a seminal article by Diewert (1976) it was shown that these indices are superlative, i.e., they are consistent with the change in wage costs when the economic framework is approximated with second-order accuracy. In particular, the Törnqvist index is exact if the cost function in the economic system is of translog form. Since both the Fisher and the Törnqvist indices score high on both axiomatic and economic test criteria they are considered by many to be superior indices. We choose the Törnqvist index as our concept of the “true” index among continuing workers since it holds desirable axiomatic and economic properties, and since it is often used to control for worker characteristics in the literature.

The impact on wages and labour services from entering and exiting workers will be

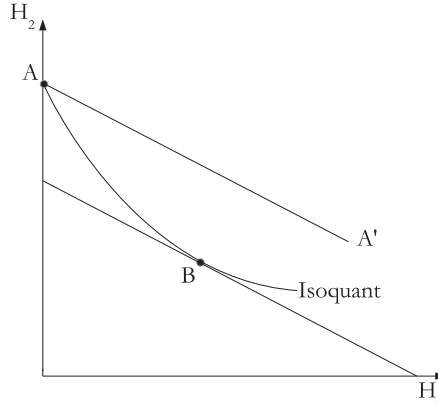


FIGURE 3.2: Impacts on wage costs from workers entering and exiting employment.

analysed using the theory of new goods. We apply the results in Feenstra (1994) where the focus of analysis was the construction of a price index when the set of goods available at time t and $t - 1$ differed. In the following, we first illustrate diagrammatically how entering and exiting workers impact wages. Second, we show explicitly how to construct an index for labour services which takes into account different sets of workers across time periods and this index is further decomposed into indices for continuing, entering and exiting workers.

Figure 3.2 illustrates the theory underlying the impact on wage costs from workers entering and exiting employment. The isocost line AA' shows the combination of hours worked between the two workers which yields the same cost for the firm. If the firm's objective is to minimise costs for a given level of production, the problem is to find a point on the isoquant where the associated isocost curve has the minimal vertical intercept. At time $t - 1$, it is only worker H_2 that is available and employment is at point A . At time t , however, both workers are available for the firm. When both workers are available, the isocost curve with the minimal vertical intercept goes through point B . The entry of a new worker thus enables the firm to reduce costs for a given level of production.

The size of the wage cost reduction depends on the curvature of the isoquant, or how easy it is to substitute one worker for another. When there is some sort of complementarity between workers, i.e., a worker's efficiency increases when working with others, the isoquant line will show a curvature as illustrated in Figure 3.2. However, if workers are perfect substitutes, the isoquant is a straight line, and there is no longer a wage cost reduction from having a new worker available for production and there is no bias from

using conventional wage indices. Importantly, absence of a new worker bias does not require workers to be homogeneous with identical wages. As illustrated in Figure 3.2, worker H_2 has a higher wage than worker H_1 , which reflects that they have different qualities. That workers may earn different wage rates is thus unrelated to the question of a new worker bias. The new worker bias is a result of the curvature of the isoquant, not the slope of the isocost function.

Figure 3.2 can also be used to illustrate the wage increase when a worker exits the labour market. When both workers are available, the isocost curve with the minimal vertical intercept goes through point B . If worker H_1 exits the labour market at time t , the firm will only employ worker H_2 (point A), which increases the wage cost for a given amount of production.

Feenstra (1994) showed the intuitive results described above analytically in the case of constant elasticity of substitution (CES) production technology, based on the Sato-Vartia index (Sato, 1976; Vartia, 1976). Consider the CES cost function for one unit of output $(\sum_{i \in I_t} b_i W_{it}^{1-\sigma})^{\frac{1}{1-\sigma}}$ where σ is the elasticity of substitution which is assumed to exceed unity and where b_i is a quality parameter for worker i .¹³ Given that the set of workers available is fixed between time periods and given by $I = I_t = I_{t-1}$, the Sato-Vartia index shows the wage index for a given unit of output. It is a geometric mean of the individual wage changes across continuing workers

$$\prod_{i \in I} (W_{it}/W_{it-1})^{x_{it}(I)}, \quad (3.5)$$

where the weights $x_i(I)$ are constructed from the expenditure shares by the relationships

$$s_{it}(I) = \frac{V_{it}}{\sum_{i \in I} V_{it}} \quad (3.6)$$

$$x_{it}(I) = \left(\frac{s_{it}(I) - s_{it-1}(I)}{\ln s_{it}(I) - \ln s_{it-1}(I)} \right) / \sum_{i \in I} \left(\frac{s_{it}(I) - s_{it-1}(I)}{\ln s_{it}(I) - \ln s_{it-1}(I)} \right). \quad (3.7)$$

Note that the Sato-Vartia wage index in Equation 3.5 does not depend on the unknown quality parameters b_i , $i \in I$. Also, although the Sato-Vartia index is consistent with the CES function it violates the monotonicity axiom, see Reinsdorf and Dorfman (1999). The index in Equation 3.5 requires that the same workers are working in both time periods. Feenstra (1994) generalised this result to also take into account that the set of workers (goods) might differ between time periods. More specifically, Feenstra (1994) showed that when the sets I_t and I_{t-1} differ, the total wage index is given by the product of the Sato-Vartia index in Equation 3.5 and two adjustment factors for entering and

¹³ If $\sigma < 1$, all workers are needed to achieve positive production, see Feenstra (1994, p. 159).

exiting workers

$$\left(\frac{W_t}{W_{t-1}}\right) = \underbrace{\left(\prod_{i \in I} (W_{it}/W_{it-1})^{x_{it}(I)}\right)}_{\text{CONTINUING}} \times \underbrace{\left(\lambda_t^{\frac{1}{\sigma-1}}\right)}_{\text{ENTERING}} \times \underbrace{\left(\lambda_{t-1}^{-\frac{1}{\sigma-1}}\right)}_{\text{EXITING}}. \quad (3.8)$$

Henceforth, the index in Equation 3.5 will be referred to as the *Sato-Vartia-Feenstra index*. λ_r is the fraction of labour costs of the workers available at both time periods, $i \in I$, relative to labour costs aggregated across the entire set of workers $i \in I_r$ at time r , i.e.,

$$\lambda_r = \frac{\sum_{i \in I} V_{ir}}{\sum_{i \in I_r} V_{ir}}, \quad \text{for } r = t-1, t. \quad (3.9)$$

$\lambda_t^{\frac{1}{\sigma-1}}$ measures the impact from new or entering workers. For example, the higher the share of new workers, the smaller the value of λ_t and the lower the value of the Sato-Vartia-Feenstra wage index. Note that the introduction of new workers cannot lead to a higher wage index. The impact from exiting workers is opposite. If the share of workers exiting employment in $t-1$ is large, λ_{t-1} becomes small which raises the wage index. The extent to which new workers lower the wage index, and the extent to which exiting workers increase the wage index, depends on the elasticity of substitution σ . As illustrated diagrammatically in Figure 3.2, when workers are perfect substitutes, the elasticity of substitution goes towards infinity ($\sigma \rightarrow \infty$), the isoquant becomes linear and the impact from new workers $\lambda_t^{\frac{1}{\sigma-1}}$ goes to unity. Consequently, new workers will not reduce the wage index when workers are perfect substitutes. Correspondingly, when workers are perfect substitutes, the impact from exiting workers will not increase the wage index as $\lambda_{t-1}^{-\frac{1}{\sigma-1}}$ goes towards unity.

We will use the case of perfect substitutes as the main alternative index from which we evaluate standard practice.¹⁴ We will refer to this index as the “true” index. When workers are perfect substitutes it follows that any change in labour costs from entering or exiting workers is due to a change in labour services only and there is thus no impact from wage changes. The “true” index for labour services can therefore be decomposed by substituting the impact from entering and exiting workers on labour costs in Equation 3.2

¹⁴In the empirical section we conduct robustness checks by allowing for different elasticities of substitution.

as¹⁵

$$\begin{aligned} \left(\frac{H_t}{H_{t-1}} \right)_{\text{TOTAL}}^{\text{True}} &= \left(\frac{H_t}{H_{t-1}} \right)_{\text{CONTINUING}}^{\text{Törnqvist}} \\ &\times \underbrace{\left(1 + \sum_{i \in I_t^c} V_{it} / \sum_{i \in I} V_{it} \right)}_{\text{ENTERING}} \times \underbrace{\left(1 + \sum_{i \in I_{t-1}^c} V_{it-1} / \sum_{i \in I} V_{it-1} \right)^{-1}}_{\text{EXITING}}. \end{aligned} \quad (3.10)$$

Note that we defined the index across continuing workers by the Törnqvist and not the Sato-Vartia index. This is due to the desirable properties of the Törnqvist index and since this index is often applied in the literature using the two-step procedure to control for worker characteristics. Note also that the case of perfect substitutes is consistent with the procedure of constructing elementary aggregates when calculating indices. For example, in the consumer price index an elementary aggregate is a group of relatively homogenous products. An elementary aggregate in the calculation of labour services would correspondingly consist of workers that are as similar as possible. Ideally, an elementary aggregate is defined by an elasticity of substitution equal to infinity within each group. Since the aggregate entering and exiting effects are a weighted average of the entering and exiting effects in each elementary aggregate, and since the Törnqvist index is approximately consistent in aggregation (Diewert, 1978), the index in Equation 3.10 approximates an index based on elementary aggregates. Equation 3.10 is therefore our benchmark “true” index from which the standard practice of using hours worked will be evaluated. While the bias from using hours worked among continuing workers and an index for labour services based on an acceptable index formula is well known from e.g., the results in Párnitzky (1974) and Diewert and Lippe (2010), the biases from entering and exiting workers will be further analysed. To this we now proceed.

3.2.3 Decomposing the biases of entering and exiting workers

In the previous two sections, the impact from entering and exiting workers has been established both for the change in hours worked in Equation 3.4 and for the theoretical index Equation 3.10. In this section we compare these indices and explicitly state the bias from using hours worked.

We define the total bias by the ratio of the true index to hours worked. As with the indices for wages and labour services, the total bias can then be decomposed into the

¹⁵The “True” index for labour services follows from the product rule by dividing Equation 3.2 with Equation 3.8 using the Törnqvist quantity index and letting $\sigma \rightarrow \infty$.

biases of continuing, entering and exiting workers

$$\text{TOTAL BIAS} = \text{CONTINUING BIAS} \times \text{ENTERING BIAS} \times \text{EXITING BIAS}.$$

The continuing bias has been extensively analysed in the literature and it measures compositional effects among continuing workers, see e.g., Diewert and Lippe (2010). The problem arises because hours worked from labour of different types are added together in Equation 3.3. For example, consider the case when the hourly wage rate of all persons is constant from one period to the next and assume further that there is a shift in demand towards lower paid labour. Since wage rates are constant, an aggregate wage index which satisfies the identity test, such as the Sato-Vartia index in Equation 3.5 or the Törnqvist index, equals unity. However, since it was assumed that there was a shift in demand towards lower paid labour, the “average” unit value has decreased, resulting in a lower unit value wage index. The product mix towards lower paid labour thus causes a downward bias in the measurement of labour services: the CONTINUING BIAS is less than unity. In other words, the unit value wage index fails the identity test, i.e., if the wage of every person is identical during the two periods, then the wage index should equal unity. The unit value index also fails the axiomatic test of homogeneity (unless relative quantities do not change), i.e., if each price in the base period increases by a factor then the index should also increase by the same factor, a property regarded to be fundamental by most index number theorists, see ILO et al. (2009, Section 17.37). Also, it fails the mean value tests and it is not invariant to changes in the units of measurement (ILO et al., 2009, Sections 2.22 and 2.25).

The main focus of this chapter is on the two last biases, the entering bias and the exiting bias. Dividing the last two terms in Equation 3.10 with the last two terms in Equation 3.4 yields

$$\text{ENTERING BIAS} = \left(\frac{1 + \sum_{i \in I_t^e} V_{it} / \sum_{i \in I} V_{it}}{1 + \sum_{i \in I_t^e} H_{it} / \sum_{i \in I} H_{it}} \right), \quad (3.11)$$

$$\text{EXITING BIAS} = \left(\frac{1 + \sum_{i \in I_{t-1}^e} V_{it-1} / \sum_{i \in I} V_{it-1}}{1 + \sum_{i \in I_{t-1}^e} H_{it-1} / \sum_{i \in I} H_{it-1}} \right)^{-1}. \quad (3.12)$$

Both of these biases relate to the relative value of labour costs to hours worked of either entering to continuing or exiting to continuing workers. In particular, if the unit value wage of entering workers are lower than the unit value wage of continuing workers, the entering bias is lower than unity, and using hours worked will overestimate the level of labour services. The reason is that the index using hours worked is based on each hour being equally important for the development of the index. However, if the unit value wage of entering workers is lower than the unit value wage of continuing workers,

there are more “low productive” workers entering employment, and these hours should from theory be valued by their labour cost contribution, not the contribution from the amount of hours worked. Correspondingly, if the unit value wage of exiting workers is lower than the unit value wage of continuing workers, the exiting bias is higher than unity and using hours worked will underestimate the level of labour services.

These relationships can be seen more clearly by defining the unit value wage u by the aggregate labour costs relative to the number of hours worked, i.e., $u_t(Z) = \sum_{i \in Z} V_{it} / \sum_{i \in Z} H_{it}$ in any given set Z . The biases above can then be approximated by¹⁶

$$\text{ENTERING BIAS} \approx \left(\frac{u_t(I_t^c)}{u_t(I)} \right)^{\omega_t}, \quad (3.13)$$

$$\text{EXITING BIAS} \approx \left(\frac{u_{t-1}(I_{t-1}^c)}{u_{t-1}(I)} \right)^{-\omega_{t-1}}. \quad (3.14)$$

where the weight ω is defined as the ratio of hours worked of entering or exiting workers to continuing workers, respectively, i.e., $\omega_r = \left(\frac{\sum_{i \in I_r^c} H_{ir}}{\sum_{i \in I} H_{ir}} \right)$ for $r = t-1, t$. For example, consider the case when the unit value of new workers is 80 per cent the unit value of continuing workers, and the hours worked by entering workers is 5 per cent the hours worked of continuing workers. Using hours worked as an index for labour services will then lead to an overvaluation of labour services by approximately 1 percentage points, i.e., $\text{ENTERING BIAS} = 0.8^{0.05} = 0.99$. In contrast, if the unit value of exiting workers is 80 per cent the unit value of continuing workers, and the hours worked by exiting workers is 5 per cent the hours worked of continuing workers, this will lead to an undervaluation of labour services by approximately 1 percentage point, i.e., $\text{EXITING BIAS} = 0.8^{-0.05} = 1.01$.

3.2.4 The two-step procedure – controlling for worker characteristics

The literature that tries to control for the “quality” of labour divides the labour force into different groups defined by characteristics such as education, age, sex etc and then in a second step, applies a proper index, such as the Törnqvist index, to aggregate these groups. In this section we analyse the theoretical rationale for this two-step procedure and show that it may amplify the problems caused using hours worked as an index for labour services.

We divide the workforce into two complement sets consisting of those that are skilled (S) and those that are unskilled (U) so that $I_t = S_t \cup U_t$. We also maintain the notation used so far, so e.g., S_t^c represents the set of skilled workers entering the workforce at time

¹⁶See the appendix, Section B.1.

t , S_{t-1}^c represents the set of skilled exiting the workforce at time $t - 1$ and S represents the set of skilled workers that are continuing. It follows that the aggregate number of hours worked by for example skilled workers can be written as $\sum_{i \in S_t} H_{it}$. The Törnqvist index across skilled and unskilled labour can then be written as

$$\left(\frac{H_t}{H_{t-1}} \right)_{\text{TOTAL}}^{\text{Two-step}} = \left(\frac{\sum_{i \in S_t} H_{it}}{\sum_{i \in S_{t-1}} H_{it-1}} \right)^{\overline{v_t(S_t, I_t)}} \left(\frac{\sum_{i \in U_t} H_{it}}{\sum_{i \in U_{t-1}} H_{it-1}} \right)^{(1 - \overline{v_t(I_t, t)})}, \quad (3.15)$$

where $v_t(S_t, I_t) = \sum_{i \in S_t} V_{it} / \sum_{i \in I_t} V_{it}$ is the labour cost share of high skilled and where the overline is the moving average operator between time $t - 1$ and t , i.e., $\overline{v_t(S_t, I_t)} = 1/2 [v_t(S_t, I_t) + v_{t-1}(S_{t-1}, I_{t-1})]$. This expression can be compared to the index in Equation 3.4. The total bias between these indices can also be split into three components: the bias of continuing workers, the bias of entering workers and the bias of exiting workers. The bias of continuing workers from the two-step procedure was analysed in e.g., Diewert and Lippe (2010). They found that the bias decreases with increased disaggregation if there are compositional effects between the groups that contribute most to the overall bias. The bias of entering and exiting workers between the group based index and hours worked differs from the entering and exiting bias based on the theoretical index. As an approximation, the two-step entering bias, can be written¹⁷

$$\text{TWO-STEP ENTERING BIAS} \approx_e \left(\frac{\overline{v_t(S_t, I_t)} - \psi_t(S, I)}{\left(\frac{\sum_{i \in S_t^c} H_{it}}{\sum_{i \in S} H_{it}} \right) - \left(\frac{\sum_{i \in U_t^c} H_{it}}{\sum_{i \in U} H_{it}} \right)} \right), \quad (3.16)$$

where the weight $\psi_t(S, I)$ is the high skilled hours worked share of continuing workers evaluated at time t , i.e. $\psi_t(S, I) = \left(\frac{\sum_{i \in S} H_{it}}{\sum_{i \in I} H_{it}} \right)$. The bias is larger than unity if both brackets are positive (or if both are negative). The first bracket is positive if high skilled workers are paid more than low skilled workers and the high skilled hours worked share of continuing workers is the same as high skilled hours worked share for all workers, i.e., if $\psi_t(S, I) \approx \psi_t(S_t, I_t)$. The second bracket is positive if skilled entry is proportionally larger than unskilled entry. To see this, let the weight $\theta_t = \left(\frac{\sum_{i \in S} H_{it}}{\sum_{i \in U} H_{it}} \right)$ denote the ratio of skilled to unskilled man-hours across continuing workers at time t . The last bracket will then be positive if skilled entry exceeds weighted unskilled entry, i.e., $\sum_{i \in S_t^c} H_{it} > \theta_t \sum_{i \in U_t^c} H_{it}$. For example, if there are twice as many skilled man-hours compared with unskilled man-hours among continuing workers ($\theta_t = 2$) and there are 1 million unskilled man-hours entering the labour market, there must be more than 2 million skilled man-hours entries for the two-step entering bias to be larger than unity.

¹⁷See the appendix, Section B.2.

Correspondingly, the two-step exiting bias can be approximated by¹⁷

$$\text{TWO-STEP EXITING BIAS} \approx e^{\left(\frac{v_t(S_t, I_t) - \psi_t(S, I)}{v_t(S_t, I_t) - \psi_t(S, I)} \right) \left[\left(\frac{\sum_{i \in U_{t-1}^c} H_{it}}{\sum_{i \in U} H_{it}} \right) - \left(\frac{\sum_{i \in S_{t-1}^c} H_{it}}{\sum_{i \in S} H_{it}} \right) \right]} \quad (3.17)$$

The bias is larger than unity if both brackets are positive (or if both are negative). The first bracket is positive if skilled workers are paid more than unskilled workers and the skilled hours worked share of continuing workers are the same as skilled hours worked share for all workers, i.e., if $\psi_t(S, I) \approx \psi_t(S_t, I_t)$. The second bracket is positive if unskilled exit is proportionally larger than skilled exit. In particular, the last bracket is positive if $\theta_{t-1} \sum_{i \in U_{t-1}^c} H_{it} > \sum_{i \in S_{t-1}^c} H_{it}$, where the weight $\theta_{t-1} = \left(\frac{\sum_{i \in S} H_{it-1}}{\sum_{i \in U} H_{it-1}} \right)$ denotes the man-hour ratio of skilled to unskilled continuing workers at time t . For example, if there are twice as many skilled man-hours compared to unskilled man-hours among continuing workers ($\theta_{t-1} = 2$) and there are 1 million unskilled man-hours exiting the labour market, there must be less than 2 million skilled man-hours exiting the labour market for the bias to be greater than unity.

The purpose of splitting the workforce into groups and then aggregating using for example a Törnqvist index is to reduce the bias from using hours worked. It is thus of particular interest to analyse whether the two-step procedure actually reduces the overall bias, e.g., to analyse when the theoretical entering and exiting biases in Equation 3.13 and Equation 3.14 will be below unity and at the same time, the group biases in Equation 3.16 and Equation 3.17 will be above unity. Explicitly, the two-step procedure will amplify the problem caused by using hours worked if there are a large number of newly educated skilled workers entering the labour force with a relatively low wage. In this case, the relatively low wage of the newly educated workers leads to an entering bias lower than unity in Equation 3.13. In contrast, since skilled workers overall have a higher wage than unskilled, the two-step entering bias is larger than unity in Equation 3.16. The two-step procedure will also worsen the problem when there are a large number of unskilled workers exiting the labour market with a relatively high wage. In this case, the relatively high wage of the unskilled leads to the exiting bias in Equation 3.14 being lower than unity. In contrast, since unskilled workers earn less than skilled, the two-step exiting bias in Equation 3.17 will be above unity. These examples illustrate that there can be situations where the 2-step procedure yields entering and/or exiting effects that are further away from the true indices than the standard practice of using hours worked.

Importantly, the two-step procedure can also exacerbate the overall bias even though the individual entering or exiting biases are reduced. This occurs when there are asymmetric reductions in biases from exiting and entering workers. To illustrate, consider the case

when the overall bias is lower than unity due to for example a large entry of workers with relatively low wages. Also, let the bias from exiting workers be larger than unity due to a lower wage among workers exiting employment. If skilled entry is proportionally equal to unskilled entry, the two-step entry bias in Equation 3.16 will be unity. But, if there is a large number of unskilled workers that exit employment with relatively low wages, both the exiting bias and the two-step exiting bias are above unity. Although the two-step procedure has reduced the exiting bias, since the exiting bias is above unity while the overall bias is below unity, a reduction of the exiting bias exacerbates the overall bias. Whether the two-step procedure actually worsens the problem of using hours worked as a quantity index, also depends on the two-step bias of continuing workers. In the empirical section, we decompose these effects separately.

3.3 Data

Our dataset holds information about hours worked and labour costs for all employed persons in Norway between 2002 and 2008. It is based on information from the Register of Employers and Employees and the Pay Statements Register. Labour costs are measured by wage income and include wages and other remunerations. It also includes income earned at sea and company benefits such as a car or a phone. Wage per hour are constructed as annual labour costs divided by contractual annual working hours. We have trimmed the data by removing workers with a registered hourly wage above NOK 4 000 and below NOK 40. Workers registered with more than 4 000 working hours a year were also removed. As a robustness check, we changed cut-off points to workers earning more than NOK 5 000 and less than NOK 30, and workers with more than 5 000 working hours. This way of treating the data was also compared with not trimming the data. In total, our benchmark trimmed dataset holds 2.9 million annual observations, which amounts to 98 per cent of the total number of observations. The results presented below are not sensitive to the level of trimming. In the appendix, Section B.3, we compare our measure of contractual hours with the measure of actual hours worked in the National Accounts. Further details about the register-based micro data and how they compare to data from e.g., the Labour Force Survey can be found in Villund (2009) and Aukrust et al. (2010). Information about worker's level of education is taken from the Population's level of education statistics.¹⁸ There are ten educational levels based on the revised Norwegian Standard Classification of Education (NUS2000): 0–No education and preschool education, 1–Primary education, 2–Lower secondary education, 3–Upper secondary (basic), 4–Upper secondary (final year), 5–Post-secondary

¹⁸See <https://www.ssb.no/en/utdanning/statistikker/utniv>

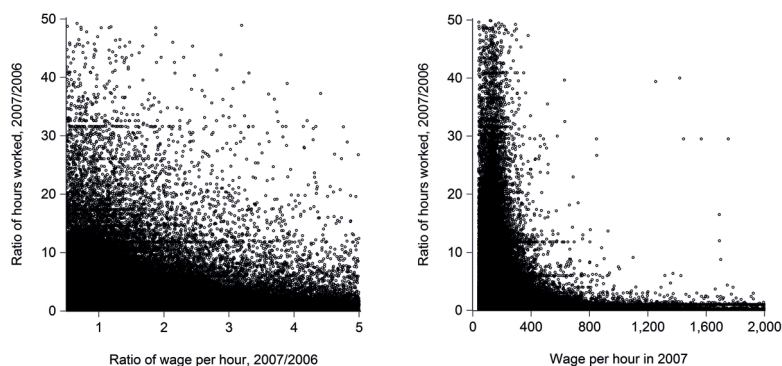


FIGURE 3.3: Wages and hours worked. The left panel shows the ratio of hours worked and the ratio of wage per hour between 2007 and 2006. The right panel shows the ratio of hours worked between 2007 and 2006 and wage per hour in 2007. Source: Statistics Norway, authors' calculations.

non-tertiary education, 6–First stage of tertiary education (undergraduate level), 7–First stage of tertiary education (graduate level), 8–Second stage of tertiary education, graduate level, 9–Unspecified. We define high skilled as workers with a NUS2000 level from 4–8, i.e., from Upper secondary final year to the second stage of tertiary education. Low skilled is thus defined as workers with no education to basic upper secondary education, and it also covers workers with an unspecified level of education. About 1.5 per cent of the workers are registered with an unspecified level of education. Most of these are immigrants.

Figure 3.3 shows descriptive evidence for wages and hours worked. The left panel shows the ratio of hours worked and the ratio of wage per hour between 2007 and 2006. There is a clear negative correlation between growth in hours worked and growth in wages. The right panel shows the ratio of hours worked between 2007 and 2006 and wage per hour in 2007. There is also a clear negative correlation between growth in hours worked and the wage level. From theory we know that a negative correlation between wage changes and changes in hours worked yields a positive bias between the Laspeyres index and the Paasche index, see e.g., ILO et al. (2004a, p. 285). We also know that a negative correlation between the wage level and changes in hours worked yields a positive bias between the overall change hours worked and for example the Törnqvist or Fisher index, see e.g., Diewert and Lippe (2010). The extent to which the negative correlations shown in Figure 3.3 impact the indices for labour services will be further analysed in the empirical section.

3.4 Empirical results

We now turn to our empirical findings based on the theoretical framework in Section 3.2. We start by decomposing labour costs into wage changes and labour services changes using the standard practice. Second, we take a closer look how indices such as Laspeyres, Paasche, Törnqvist and Fisher compare with the standard practice when calculated across continuing workers. Third, based on the theory of entering and exiting workers, we compare the standard practice with our preferred “true” index and decompose the contributions from continuing, entering and exiting workers. Forth, we analyse how controlling for the level of education using the two-step procedure performs empirically. Fifth, we conduct a robustness analysis allowing for different elasticities of substitution in our definition of the “true” index. Lastly, we show how mismeasurement of labour services using the standard practice has impacted the development of productivity in Norway.

3.4.1 Decomposing labour costs using the standard practice

In Table 3.1 we show the results of decomposing the logarithmic change in labour costs into its respective price and quantity components applying the unit value index. Labour services are thus measured by hours worked, see Equation 3.4. Labour costs growth was temporarily reduced to 3.29 per cent in 2003 before increasing to 10.15 per cent in 2008. The contribution from continuing, entering and exiting workers changed during this time period. From 2002 to 2005 the contribution from continuing workers was higher than the total figure, indicating that the impact from exiting workers outweighed the impact from entering workers. In tandem with a booming economy and an increase in immigration after 2005, the impact from entering workers increased and the reduction in wage costs from exiting workers was reduced. Nevertheless, the large increase in total labour costs was due to an increase in labour costs among continuing workers. Growth in labour costs is decomposed into wage growth and growth in labour services. From 2002 to 2005 most of the labour cost growth was attributed to wage growth. After 2005, a larger portion of the total labour cost growth is due to labour services growth, measured by hours worked. Workers entering the workforce reduced total wages by between 1.3 and 1.8 percentage points. In contrast, exiting workers contributed to an increase in total wages between 0.8 and 1.0 percentage points. As a result, the impact from entering workers is larger than from exiting workers. The increased negative impact on unit values from entering workers after 2005 may reflect the relatively low wages paid to immigrants in conjunction with the large increase in immigration.

TABLE 3.1: Decomposing labour costs using unit values

	Labour costs			Wages (Unit values)			Labour services (Hours worked)		
	Total	Continuing	Entering	Exiting	Total	Continuing	Entering	Exiting	Exiting
2002	5.70	6.30	5.33	-5.92	4.52	5.11	-1.60	1.01	1.18
2003	3.29	4.40	5.20	-6.31	3.68	4.25	-1.43	0.86	-0.39
2004	3.92	4.09	4.78	-4.95	2.87	3.20	-1.33	1.00	1.05
2005	4.68	5.24	4.32	-4.88	4.64	5.09	-1.49	1.03	0.04
2006	8.20	7.53	5.42	-4.76	4.85	5.81	-1.78	0.81	3.35
2007	9.34	8.91	5.22	-4.79	5.85	6.84	-1.79	0.80	3.49
2008	10.15	8.91	5.66	-4.43	5.56	6.51	-1.76	0.81	4.59
									2.40
									7.43
									-5.23

The product rule of indices (Value index = Price index \times Quantity index) is decomposed using unit values as the price index into contributions from continuing, entering and exiting workers. Measured as the logarithmic difference in per cent. Source: Statistics Norway, authors' calculations.

TABLE 3.2: Labour services across continuing workers. Growth rates.

	Hours worked	Törnqvist I ^a	Törnqvist II ^b	Fisher	Laspeyres	Paasche
2002	1.19	0.65	0.57	0.29	4.46	-3.87
2003	0.15	-0.32	-0.31	-0.75	3.10	-4.59
2004	0.89	0.24	0.20	-0.13	3.50	-3.75
2005	0.14	-0.50	-0.57	-0.96	2.43	-4.35
2006	1.72	1.10	0.91	0.77	4.19	-2.65
2007	2.07	1.00	0.81	0.56	3.97	-2.84
2008	2.40	1.62	1.47	1.29	4.75	-2.18

^a Measured directly using the Törnqvist quantity index: $\prod (H_{it}/H_{it-1})^{1/2(s_{it}+s_{it-1})}$.

^b Measured indirectly from the Törnqvist price (wage) index by applying the product rule: $(\sum V_{it}/\sum V_{it-1})/\prod (W_{it}/W_{it-1})^{1/2(s_{it}+s_{it-1})}$.

Measured as the logarithmic difference in per cent. Source: Statistics Norway, authors' calculations.

3.4.2 Comparing standard practice with other classical indices

Table 3.2 shows the logarithmic change of different indices for labour services across continuing workers only. There are large differences across the measures of labour services. *Törnqvist I* is based on a Törnqvist quantity index. Overall, the annual growth is lower than for hours worked, approximately 0.5 – 1 percentage points. Correspondingly, wage growth is overvalued by 0.5 – 1 percentage points. Note that the increase in labour services from 2005 to 2008 is about at the same level as for hours worked. Interestingly, for some years there is a significant difference between the Törnqvist quantity index and the quantity index measured indirectly using a Törnqvist wage index and the product rule, referred to as *Törnqvist II*. This discrepancy is increasing somewhat in the years after 2005. Also, the Fisher index shows lower growth than the other indices. As illustrated by Dumagan (2002), this may reflect large variations in wage shares and hours worked across time. These patterns should also be seen in conjunction with the discrepancy between the Laspeyres and the Paasche indices in Table 3.2. A positive bias between the Laspeyres index and the Paasche index occurs when there is a negative correlation between price *changes* and volume changes, see e.g., ILO et al. (2004a, p. 285). There has thus been a large shift towards using labour that has become cheaper. In contrast, the bias between hours worked (unit value index) and for example the Fisher index is driven by a correlation between the wage *level* and volume changes. Consequently, Table 3.2 also shows that there has been a large increase in employment among workers with low wage levels.

TABLE 3.3: Comparing standard practice with the true index

	Hours worked ^a			True index ^b			Bias		
	Total	Continuing	Entering	Exiting	Total	Continuing	Entering	Exiting	Exiting
2002	1.18	1.19	6.93	-6.93	0.05	0.65	5.33	-5.92	-1.13
2003	-0.39	0.15	6.63	-7.17	-1.43	-0.32	5.20	-6.31	-1.04
2004	1.05	0.89	6.11	-5.95	0.07	0.24	4.78	-4.95	-0.98
2005	0.04	0.14	5.81	-5.91	-1.07	-0.50	4.32	-4.88	-1.10
2006	3.35	1.72	7.20	-5.57	1.77	1.10	5.42	-4.76	-1.58
2007	3.49	2.07	7.01	-5.59	1.42	1.00	5.22	-4.79	-2.07
2008	4.59	2.40	7.43	-5.23	2.86	1.62	5.66	-4.43	-1.73

^a Hours worked is exactly decomposed into continuing, entering and exiting workers using the identity Equation 3.4.

^b The true index is the sum of the contributions from continuing workers (Törnqvist) and entering and exiting workers when workers are assumed to be perfect substitutes, see Equation 3.10.

Measured as the logarithmic difference in per cent. Source: Statistics Norway, authors' calculations.

3.4.3 Comparing standard practice with the true index

Table 3.3 compares the standard practice using hours worked as a measure for labour services with the true index calculated both across continuing, entering and exiting workers, as defined in Equation 3.4 and Equation 3.10. As mentioned, the Törnqvist quantity index is chosen as the preferred alternative index since this index is often used in the literature to control for compositional effects and it holds desirable axiomatic and theoretical properties. The table shows the biases between the standard practice and the true index, in particular the entering and exiting biases as defined in Equation 3.11 and Equation 3.12. The total bias in hours worked ranges from -1 to -2 percentage points annually. The bias of the wage index will thus correspondingly range from 1 to 2 percentage points annually. About half of this bias is attributed to compositional effects among continuing workers and half of this bias is attributed to the impact from entering and exiting workers. Note that the bias from entering workers ranges from -1.3 to -1.8 percentage points, but is somewhat offset by the bias from exiting workers which ranges from 0.8 to 1.0 percentage points. Interestingly, the overall bias increases (in absolute value) after 2005, which is the period when productivity growth in Norway decreased.

3.4.4 The two-step procedure – controlling for the level of education

Table 3.4 compares the standard practice for hours worked with the Törnqvist index across hours worked in two educational groups, as the approximations in Equation 3.16 and Equation 3.17 illustrates. In contrast to the negative bias between the “true” index and hours worked, the total bias when aggregating across two educational groups is positive from 2002 to 2006. About a third of this bias is due to continuing workers. From the results in (Diewert and Lippe, 2010, p. 704), we know that this is caused by compositional effects within groups being dominant. Interestingly, most of the total bias is a result of exiting workers. The reason is, however, not that the bias for exiting workers has the “wrong” sign with respect to the true index. It is rather caused by the biases from entering and exiting workers having opposite signs and it is mostly the exiting effect which is controlled for in the two-step procedure. As the overall bias is negative and the exiting bias in Table 3.3 is positive, the two-step procedure exacerbates the overall bias since it is the exiting bias that is mostly reduced. Towards the end of the sample period, the total bias changes from being positive to being negative, a change mainly caused by an increased negative bias among entering workers. From Equation 3.16 this is caused by the weighted number of unskilled entries into the labour market exceeding the number of skilled entries, which should be viewed in light of the large increase in immigration during this time period.

TABLE 3.4: Labour services, controlling for the level of education: two-step aggregation

	Hours worked ^a			Two-step index (two educational groups) ^b			Bias		
	Total	Continuing	Entering	Exiting	Total	Continuing	Entering	Exiting	Exiting
2002	1.18	1.19	6.93	-6.93	1.35	1.25	6.93	-6.83	0.16
2003	-0.39	0.15	6.63	-7.17	-0.21	0.21	6.63	-7.05	0.18
2004	1.05	0.89	6.11	-5.95	1.20	0.95	6.09	-5.84	0.15
2005	0.04	0.14	5.81	-5.91	0.14	0.19	5.76	-5.81	0.11
2006	3.35	1.72	7.20	-5.57	3.42	1.76	7.12	-5.46	0.06
2007	3.49	2.07	7.01	-5.59	3.44	2.07	6.84	-5.48	-0.05
2008	4.59	2.40	7.43	-5.23	4.43	2.38	7.19	-5.13	-0.16

^a Hours worked is exactly decomposed into continuing, entering and exiting workers using the identity Equation 3.4.

^b The two-step procedure is based on two educational groups, where high skilled are defined as workers with a NUS2000 level from 4-8, i.e., from upper secondary final year to the second stage of tertiary education. The aggregate index is calculated as a Törnqvist index of the two groups, see Equation 3.15.

Measured as the logarithmic difference in per cent. Source: Statistics Norway, authors' calculations.



FIGURE 3.4: Labour services. Index: 2001=1. Compares the index for hours worked with theoretical indices based on different values of the elasticity of substitution σ . Our definition of a “true” index is based on workers being perfect substitutes, which is obtained when the elasticity of substitution is set to infinity.

3.4.5 Robustness with respect to the elasticity of substitution

Our definition of the “true” index is based on the assumption of workers being perfect substitutes, i.e., the elasticity of substitution σ is set to infinity. Although the assumption allows for heterogenous workers earning different wages, it may be restrictive, and hence influence the overall index. In this section, we analyse how sensitive the aggregate index is to different assumptions about the elasticity of substitution. To this end, we consider the theoretical index for any value of the elasticity of substitution:¹⁹

$$\left(\frac{H_t}{H_{t-1}}\right)_{\text{TOTAL}}^{\sigma} = \left(\frac{H_t}{H_{t-1}}\right)_{\text{CONTINUING}}^{\text{Törnqvist}} \times \underbrace{\left(1 + \sum_{i \in I_t^c} V_{it} / \sum_{i \in I} V_{it}\right)}_{\text{ENTERING}} \left(\lambda_t^{-\frac{1}{\sigma-1}}\right) \times \underbrace{\left(1 + \sum_{i \in I_{t-1}^c} V_{it-1} / \sum_{i \in I} V_{it-1}\right)^{-1}}_{\text{EXITING}} \left(\lambda_{t-1}^{\frac{1}{\sigma-1}}\right),$$

where λ_r for $r = t, t-1$, defined in Equation 3.9, is the fraction of expenditure on the workers available at both time periods, $i \in I$, relative to the expenditure on the entire set of workers $i \in I_r$ at time r . Since λ_r is less than unity, it follows that a lower value of the elasticity of substitution increases the contribution from entering workers and decreases the contribution from exiting workers. In Figure 3.4, we compare the index for hours worked with the theoretical index based on different values of the elasticity

¹⁹The theoretical index follows from the product rule by dividing Equation 3.2 with Equation 3.8 using the Törnqvist quantity index.

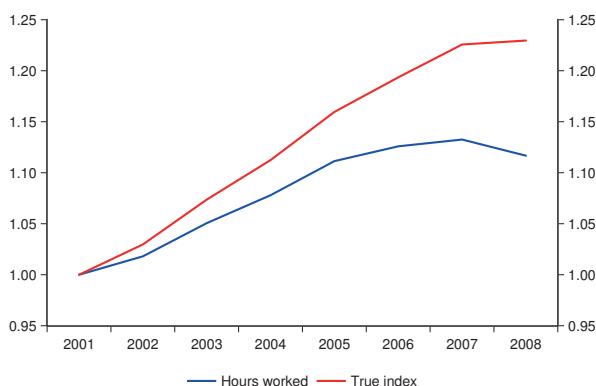


FIGURE 3.5: Labour productivity. Mainland Norway. Measured as the index for value added relative to the index for labour services, using Equation 3.10 and Equation 3.4. 2001=1.

of substitution. Interestingly, the “true” index as we define it, with an elasticity of substitution equal to infinity, represents a conservative measure throughout the sample period relative to indices based on lower values of σ . This is driven by the large effect from exiting workers between 2001 and 2005. In tandem with increased immigration after 2005, the contribution from entering workers yields a larger increase in indices with a lower σ . In 2008, all of the theoretical indices are approximately 3.6 per cent higher than the value in 2001. In contrast, the index for hours worked is 14.2 per cent higher in 2008 than the value in 2001. The overvaluation from using hours worked as an index for labour services is thus robust to different values of the elasticity of substitution.

3.4.6 Implications for productivity measurement

Figure 3.5 shows how mismeasured labour services have impacted the measured level of productivity in Mainland Norway. The series “Hours worked” represents the official index for labour productivity in Mainland Norway from Statistics Norway, normalised to unity in 2001. The series “True index” represents an adjusted series where the adjustment is the bias defined by the difference between Equation 3.10 and Equation 3.4. In contrast to what official figures shows, productivity did not drop in 2008 but increased modestly by 0.3 percent. Compared with the period between 2001 and 2005, average labour productivity growth as measured by official statistics was reduced by 2.5 percentage points in the period after 2005. Figure 3.5 shows that the bias increases in the same time period. The average total bias between 2002 and 2005 was 1.1 percentage

points and it changed to 1.8 percentage points on average from 2006 to 2008, up by 0.7 percentage points. Mismeasurement can therefore explain about a quarter of the measured drop in productivity growth after 2005.

3.5 Conclusions

The purpose of this chapter has been to analyse the measured slowdown in productivity growth in Norway after 2005. To that end, we have computed indices for labour services with good theoretical properties that take into account the effects from workers entering and exiting the workforce. We have shown theoretically the poor properties of the standard practice of using hours worked as an index for labour services. Also, we have analysed theoretically the two-step procedure often used in the literature to counteract the weaknesses with unit values and hours worked. In particular, we have shown that the two-step procedure can exacerbate the unit value bias through entering and exiting effects if there is asymmetry in the reduction of entering and exiting biases.

The theoretical results have been empirically illustrated in the case of Norway between 2002 and 2008 using register data. We found that using hours worked overestimated growth in labour services by approximately between 1 to 2 percentage points annually. Wages have been correspondingly underestimated. About half of this was attributed to a bias among continuing workers and half was attributed to the effect of workers entering and exiting employment. In addition, we found that the two-step procedure exacerbated the unit value bias in the first half of the sample when controlling for workers' level of education. Importantly, our findings show that an increasing overestimation of labour services can account for about a quarter of the measured productivity slowdown after 2005.

Chapter 4

The import price index with trade barriers: theory and evidence

Abstract: The standard economic import price index hinges on the assumption of free trade. Applying it to situations with barriers to trade yields biased results compared to a true import price index. To circumvent this problem it is common in the literature to use average prices as an aggregator function. However, average prices may still underestimate the economic effects from trade liberalisation. In this chapter, I generalise the economic import price index to allow for barriers to trade in the form of quantity constraints. To illustrate the theoretical framework, I use the case of clothing imports to Norway and show that a unit value index, which is believed to be appropriate for the aggregation of homogenous items, overestimates the annual inflation rate by 0.5 percentage points.

4.1 Introduction

As pointed out by Boskin et al. (1998, p. 3): “Accurately measuring prices and their rate of change, inflation, is central to almost every economic issue. There is virtually no other issue that is so endemic to every field of economics”. Import prices are of particular importance. Recently, import prices have been used to increase our understanding on a wide variety of areas, such as real income growth (Diewert, 2014), inequality (Bekkers et al., 2012), exchange rate pass-through (Brun-Aguerre et al., 2012) and productivity growth (Feenstra et al., 2013b). These examples illustrates the need to accurately measure import prices.

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Import prices can, however, be wrongly measured when trade barriers are present. The standard economic import price index is based on economic theory in which an establishment is assumed to minimise the expenditure necessary to reach a particular level of production for a given set of prices. Within this framework, it is assumed that the establishment is free to choose between all goods – there are no barriers to trade. If the assumption is true, the price *level* of a particular good is irrelevant for the development of the price index. However, if goods are not traded freely, which is often the case in practice, the price level becomes important for the final index number. Hence, neglecting the price level can lead to serious mismeasurement of import prices.

The reduction of implicit and explicit barriers to trade has been commonplace in the last decades. For example, explicit restrictions on imports have been widely present in textile and garment trade when it was governed by the Multi-Fibre Arrangement from 1974 to 2004. Also, there are still large barriers to trade in agriculture and the question of further trade liberalisation remains a controversial issue. Recently, the Transatlantic Free Trade Agreement is a proposed agreement between the European Union and the United States with the purpose of liberalising trade by reducing regulatory barriers and tariffs. A framework that can account for the impact of trade liberalisation on the cost of imports is thus of great relevance.

The purpose of this chapter is twofold. The first aim is to generalise the standard economic import price framework to allow for barriers to trade in the case of homogenous products. The second aim is to establish under what conditions the index serves as a conservative measure to the true index also in the case of non-homogenous goods. To illustrate the theoretical framework, I use the case of clothing imports to Norway using data between 1988 and 2012. During most of this time period, the price of clothing from China was between 40–80 per cent lower than the price of clothing from other countries. Due to a gradual removal of trade barriers, the cost share of imports from China increased from about 3 to about 50 per cent over the sample period. The empirical example illustrates that a unit value index, which is believed to be appropriate for the aggregation of homogenous items, overestimates the annual inflation rate by 0.5 percentage points.

The rest of the chapter is organised as follows. In Section 4.2, I first motivate the need for a framework that allows for barriers to trade. Second, I introduce the import price framework, and then generalise it to allow for barriers to trade. In Section 4.3, I define the bias of the standard import price index when goods are homogenous and establish under what conditions it serves as a conservative measure to the true index also in the case of non-homogenous goods. In Section 4.4, I illustrate the economic framework with an empirical example using data on imports of clothing to Norway between 1988 and

2012. Section 4.5 concludes.

4.2 Measuring import prices

To form a point of reference from which this literature has evolved it is instructive to illustrate how an ordinary index can yield biased results when applied to situations characterised by trade liberalisation. Consider the following paradox: An establishment imports shirts of identical quality from country L and H . Let p_{Lt} and p_{Ht} denote the price level in country L and H at time t , respectively. It is assumed that country L is a low cost country while country H is a high cost country ($p_{Lt} < p_{Ht}$). Moreover, inflation in country L is assumed somewhat higher than inflation in country H , i.e., measured in the logarithmic difference $\Delta \ln p_{Lt} > \Delta \ln p_{Ht}$. Due to trade barriers such as quantity constraints, the establishment cannot import as many shirts from country L as preferable. Gradually, trade barriers are reduced, and more low cost shirts are imported from country L . This new availability of low cost shirts reduces the average price the establishment has to pay for shirts. The cost of imports has been reduced. But a standard import price index would increase. To see this, consider the aggregate inflation rate from a Törnqvist price index. When there is free trade, this index approximates the true cost of imports with second order accuracy (Theil, 1967; Diewert, 1976). The aggregate inflation rate ($\Delta \ln p_t$) is given as a weighted average of the inflation rates in country L and H

$$\Delta \ln p_t = \overline{s_{Lt}} \Delta \ln p_{Lt} + (1 - \overline{s_{Lt}}) \Delta \ln p_{Ht}, \quad (4.1)$$

where $\overline{s_{Lt}} = 1/2(s_{Lt} + s_{Lt-1})$ and s_{Lt} is the value share of imports from the low cost country. The increased imports of shirts from country L , due to reduced trade barriers, increases the weight of the inflation rate in country L , and reduces the weight of the inflation rate in country H . Since inflation is assumed somewhat higher in country L than H , the overall inflation rate increases. That the standard import price index can increase, when the true cost of imports has decreased, is a paradox. The paradox is caused by the fact that the standard import price framework implicitly assumes free trade. Hence, the price *level* of a particular good is irrelevant for the development of the price index.

The literature analysing how a gradual lowering of trade barriers and an increased integration of low cost countries into the world economy have put downward pressure on inflation rates tries to circumvent this problem by looking at a weighted sum of price

levels. The geometric average price level is defined by

$$\ln p_t = s_{Lt} \ln p_{Lt} + (1 - s_{Lt}) \ln p_{Ht}. \quad (4.2)$$

Pain et al. (2006) apply this framework to identify the impact of imports from emerging markets on inflation in OECD economies; Nickell (2005) and Coille (2008) use the framework to analyse the evolution of inflation in the United Kingdom; and Benedictow and Boug (2013) use empirically a similar framework to calculate foreign price impulses to Norwegian import prices of clothing. Using an arithmetic average instead of the geometric average, Kamin et al. (2006) study the impact of Chinese exports on import prices in 26 OECD countries. Røstøen (2004) applies the arithmetic average price framework to identify external price impulses to imported consumer goods in Norway. An early reference is Griliches and Cockburn (1995) who studied the shift from branded to generic drugs. Moreover, bureaus of statistics such as Statistics Norway use an arithmetic average price framework, with quantity shares as weights (unit values), as sub-indices for homogenous product groups to calculate import price indices, see the Export and Import Price Index Manual (ILO et al., 2009, Chapter 2). The use of average prices when there is price variation for the same quality of good or service is also recommended in the SNA 2008 (European Commission et al., 2009, Paragraph 15.68). To see how the average price framework can be used to identify the impact from a gradual lowering of trade barriers on inflation, apply the quadratic approximation lemma (Diewert, 1976, p. 118) to the geometric average price level in Equation 4.2 to get the inflation rate

$$\Delta \ln p_t = \overline{s_{Lt}} \Delta \ln p_{Lt} + (1 - \overline{s_{Lt}}) \Delta \ln p_{Ht} + \Delta s_{Lt} (\overline{\ln p_{Lt}} - \overline{\ln p_{Ht}}). \quad (4.3)$$

The difference between the inflation rate from the Törnqvist price index in Equation 4.1, and the inflation rate from the geometric average price level in Equation 4.2, i.e., the term $\Delta s_{Lt} (\overline{\ln p_{Lt}} - \overline{\ln p_{Ht}})$, is interpreted as the bias from applying the standard import price index during times of trade liberalisation. If the value share of imports from the low cost country increases due to lowering of trade barriers, the bias is negative and the increased integration of low cost countries into the world economy is interpreted to have put downward pressure on inflation.

The main problem with applying a weighted average of price levels is that, to my knowledge, it cannot be linked to economic theory in the presence of trade barriers. Indeed, the inflation rate in Equation 4.3 is consistent with an import price index from a time varying Cobb Douglas production technology $u_t = x_{Lt}^{\alpha_t} x_{Ht}^{1-\alpha_t}$, where x_{Lt} and x_{Ht} are the goods from the low cost and high cost country, respectively, and α_t is a time varying technology parameter equal to s_{Lt} in equilibrium. However, within this model where trade barriers are *absent*, an increase in the import share is caused by a technological

change favouring products from the low cost country. This use of geometric average prices is therefore not suitable if the purpose is to analyse how a gradual lowering of trade barriers has affected inflation. Unit values can only be meaningfully linked to economic theory when all commodities are homogenous (perfect substitutes) and when there is no price dispersion, i.e., $p_{Lt} = p_{Ht}$, see e.g., Balk (1998a) and Bradley (2005). In contrast, import price effects from a gradual lowering of trade barriers will only exist if there is price dispersion.

Since average prices cannot be linked to an appropriate economic framework they may still yield biased results when applied to situations characterised by trade liberalisation. To illustrate, consider the example above but now assume that prices are decreasing in the low cost country and deflation occurs at a rate higher than the increase in imports, i.e., $-\Delta \ln p_{Lt} > \Delta \ln x_{Lt}$, where x_{Lt} is the quantity of imports from country L . Furthermore, assume that the total value of imports is unchanged between the two time periods. In this case, even though trade liberalisation has facilitated increased imports from the low cost country, the cost share of imports from the low cost country decreases since the price fall outweighs the quantity increase, i.e., $\Delta s_{Lt} < 0$. Accordingly, despite the lowering of import costs following the reduction in trade barriers, the term $\Delta s_{Lt}(\ln \overline{p_{Lt}} - \ln \overline{p_{Ht}})$ is positive. Hence, applying Equation 4.3 can wrongfully lead to the conclusion that trade liberalisation has led to increased import costs. In contrast to the true decrease in costs of imports due to trade liberalisation, which refers to an increase in the *quantity* of imported goods from low cost countries, the cost share s_{Lt} is affected by changes in *both* underlying prices and quantities. Equation 4.3 may therefore yield biased results also in the case of trade liberalisation. For this reason, a different approach is needed to identify a bias that can be interpreted as showing the import price effects from a reduction in trade barriers. In the following, I first outline the standard import price index based on a cost minimising establishment and then generalise the framework to allow for changes in the index due to lowering of trade barriers by building upon the theory of rationed households, see e.g., Rothbarth (1941); Tobin (1952) and Howard (1977).

4.2.1 The standard import price index

Consider a cost minimising establishment that imports goods. Let $x_t = (x_{1t}, x_{2t}, \dots, x_{nt})'$ denote a vector of quantities of imported intermediates at time t and let $p_t = (p_{1t}, p_{2t}, \dots, p_{nt})'$ be the corresponding price vector where $'$ indicates the transpose operator. Further, let $u_t = f(x_t)$ denote the establishment's production technology as a function of imported goods and let $c(p_t, u_t)$ be the input price function. Note that the functional form of the production technology encompasses the particular case when

goods are homogenous as defined by the linear functional form $u_t = \sum_{i=1}^n x_{it}$. The input price function $c(p_t, u_t)$ represents the minimal cost necessary to achieve the production level u_t at prices p_t

$$c(p_t, u_t) \equiv \min_{x_t} \{p'_t x_t : u_t = f(x_t)\}. \quad (4.4)$$

An economic import price index is the ratio of the input prices required to attain a particular level of production under two price regimes. In particular, the standard Konüs (1939) index (I_t^K) is defined as

$$I_t^K \equiv c(p_t, u_{t-1})/c(p_{t-1}, u_{t-1}). \quad (4.5)$$

Together, Equation 4.4 and Equation 4.5 constitute the standard import price framework. The index shows the change in the minimal cost necessary to sustain a given level of production when prices change between period $t - 1$ and t . From this definition, it is obvious that if prices remain unchanged between the two time periods, the import price index is unity. Any change in the import price index is therefore caused by a change in prices.

4.2.2 An import price index with trade barriers

The standard import price framework hinges on the assumption that the establishment is free to choose between all bundles of goods – there are no restrictions on the availability of goods in the definition of the import price function Equation 4.4. As a consequence, the index in Equation 4.5 yields a biased estimate of cost of imports when there are barriers to trade. In the previous section, it was shown that any change in the standard import price index must be caused by a change in prices. However, increased imports from low cost countries is not a phenomenon caused by changing relative prices or changing income. It is caused by increased availability of low cost goods and services. This increase in availability allows importers to choose from a plethora of new products which decrease their costs even when production and prices remain unchanged. An import price index that takes the effects of trade liberalisation into account should therefore decrease when the amount of available goods increases.

To be more precise, an import price index should show the ratio of the costs required to attain a particular indifference curve under two price regimes and between two different

time periods:²⁰

$$I_t \equiv c_t(p_t, u_{t-1}) / c_{t-1}(p_{t-1}, u_{t-1}). \quad (4.6)$$

Observe that the difference between this definition and the standard import price index in Equation 4.5 is the time subscript on the cost functions. Even when prices are unchanged, and production is kept constant, this index can change due to exogenous factors such as lowering of trade barriers. Moreover, note that allowing the import price index to change, when prices are unchanged, violates one of the axiomatic requirements for price indices: the *identity axiom* explicitly states that if prices are constant over the two periods being compared, then the price index should equal one (Balk, 2012, p. 58). The purpose of this article is to identify the reduction in costs from trade liberalisation; reductions that occur irrespective of price changes. To allow for such effects in an import price index, the identity property must be violated.

I proceed by defining an economy with restrictions on trade. Let the index $j \in \mathcal{J}$ run across goods where such restrictions apply. The import of any good j cannot exceed a predefined level \bar{x}_{jt} : $x_{jt} \leq \bar{x}_{jt}$. The nature of the process \bar{x}_{jt} is exogenous. It represents the restriction that hinders the importer from choosing freely between goods. Such restrictions can be due to direct quota restrictions or it can be due to the sluggish response of supply from the gradual removal of trade barriers. Incorporating these trade barrier restrictions yields a new definition of the expenditure function

$$c_t(p_t, u_t) \equiv \min_{x_t} \{p'_t x_t : u_t = f(x_t), x_{jt} \leq \bar{x}_{jt}, j \in \mathcal{J}\}. \quad (4.7)$$

It shows the minimal cost necessary to reach a particular level of production, given prices, a production technology and possible restrictions on availability. Together, Equation 4.6 and Equation 4.7 constitute the generalisation of the standard import price index framework in Equation 4.4 and Equation 4.5. If there are no trade barriers, i.e., $\bar{x}_{jt} = \infty$, $j \in \mathcal{J}$, this import price function is equivalent to the import price function in the previous section. With respect to the topic of this chapter, the standard import price framework Equation 4.4 and Equation 4.5 can thus be interpreted as a situation of free trade between countries.

The new good bias is also encompassed by this framework. Assume that a new good, say x_{jt} , is introduced in period $t = s$. Before period s , good j cannot be imported, i.e., $\bar{x}_{jt} = 0$ when $t < s$. When the new good is introduced to the market, there is no

²⁰This definition is similar to the one adopted by Feenstra (1994). It is also equivalent to equation (4) in Balk (1989), who studied time-varying preferences (or production technology). If production technology is time-varying, Equation 4.6 implies a cardinal interpretation of technology. In the context of this chapter, however, the production technology is assumed constant across time periods, and thus represents an ordinal entity.

import restriction, i.e., $\bar{x}_{jt} = \infty$ when $t \geq s$. This highlights a difference between the bias resulting from the introduction of new goods and the bias resulting from gradual removal of trade barriers: the former is a one time change in availability, while the latter is a gradual change in availability.

This difference between the new good bias and the bias arising from trade liberalisation is crucial in terms of identification. Consider for example how Hausman (1999) identified the new goods bias of cellular telephones. After these telephones were introduced to the market, Hausman (1999) estimated the demand curve and then solved for the expenditure function using Roy's identity. He identified the bias of cellular phones by solving for the price which causes the demand for cellular phones to be zero. Note that only if consumers are free to choose between all products will their pattern of consumption reveal their underlying preferences. This approach therefore depends on consumers being free to choose between the new good and other goods, i.e., $\bar{x}_{jt} = \infty$, after the new good has been introduced, $t \geq s$. The impact from trade barriers is different in this respect since the state of free trade ($\bar{x}_{jt} = \infty$, $j \in \mathcal{J}$) has not yet been reached. We have moved gradually from a state with trade restrictions to a state with less trade restrictions. In terms of identification this is a problem. If observed import patterns are the result of increased availability, and not the result of cost and relative price changes, import patterns will not reveal the form of the production technology.

This is illustrated graphically in Figure 4.1a and Figure 4.1b. Point A in Figure 4.1a shows the situation before the new good (x_1) has been introduced. This is tantamount to a situation of autarky in the international trade literature. If x_1 cannot be imported, it is only x_2 that is imported. The isoquant curve labeled U_A corresponds to the level of production reached at point A . When the economy opens up to trade, and there are no restrictions on the imports of x_1 , the optimal level of imports will be at point B . Opening up for trade increases the production of the establishment, as shown by the outward movement of the isoquant curve to U_B . Feenstra (1994) shows how to incorporate this movement from autarky to free trade into a price index when using a CES utility function. Feenstra and Weinstein (2010) show how to do it from a translog expenditure function. The new good bias thus represents two extremes: the time before the new good is introduced can be viewed as a situation of infinitely high trade barriers, and the time after the good is introduced can be viewed as there being no trade barriers. The main concern of this chapter is the situation between these two extremes, i.e., the case when there are some trade barriers that are gradually removed, see Figure 4.1b. Point \bar{A} shows the level of imports when some trade restrictions are present. Point \bar{B} shows the level of imports when fewer trade restrictions are present. The movement from \bar{A} to \bar{B} increases the level of production of the importer, i.e., the isoquant moves

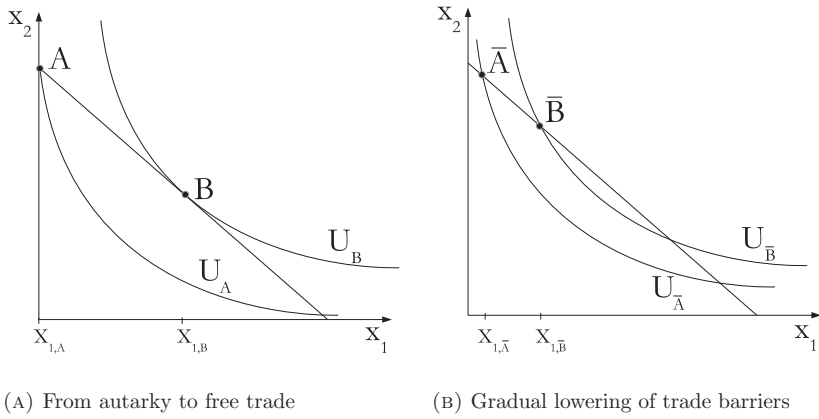


FIGURE 4.1: Effects from increased trade on import prices in the case of non-homogenous products.

outwards from $U_{\bar{A}}$ to $U_{\bar{B}}$. However, the isoquants are not in any of the states tangent to the isocost curve. Since the trade barrier restriction holds, the standard means of identifying compensating variation based on observed prices and quantities cannot be applied.

Figure 4.1 also illustrates another important difference between the new good bias and the trade barrier bias. The new goods bias refers to the decrease in costs when the new product is included in the import price index: In period A , the good x_1 is not included in the index and in period B , it is included in the index. In other words, the introduction of a new good into the index signals a potential bias. In contrast, there is no such signal of a bias arising from a gradual removal of trade barriers. The good x_1 is included in the index in both time periods. It is only outside knowledge about the existence of trade barriers that can signal a potential bias. For example, it is a historical fact that the Multi-Fibre Arrangement imposed quota restrictions on imports of textiles from China. This fact is utilised in the empirical analysis in Section 4.4 to evaluate the size of the bias in the case of textile imports to Norway.

A third and important difference between the two biases can be seen in the case of homogenous goods. The new good bias arises from the assumption that there is a production gain from increased availability of varieties – isoquants are non-linear. But if goods are homogenous, isoquants are linear and the availability of varieties has not increased. There is no “new good” bias since it is the availability of *existing* goods that has increased. In contrast, even in the case when goods are homogenous can there be a bias arising from trade liberalisation, given that importers are restricted from purchasing the lower priced good, as the next section will illustrate.

4.3 The bias of the standard import price index

The purpose of this section is to define the bias of the standard import price index due to trade barriers in the case of homogenous goods and to establish under what conditions it will serve as a conservative measure (an upper bound) to the true bias in the case of non-homogenous goods. To this end, I consider a constant elasticity of substitution (CES) production technology over n imported intermediates

$$u_t = \left(\sum_{i=1}^n \delta_i x_{it}^\rho \right)^{1/\rho}. \quad (4.8)$$

The parameter δ_i can be thought of as a measure of quality for good i and the mapping between the parameter ρ and the elasticity of substitution σ is given by $\sigma = 1/(1 - \rho)$. Goods are defined as *perfect substitutes* in the case when $\rho = 1$, i.e., the when goods are characterised by a constant technical rate of substitution. If both the technical rate of substitution is constant ($\rho = 1$) and if the quality of between two different goods are equal, i.e., $\delta_i = \delta_k$ for $i \neq k$, the goods are referred to as being *homogenous*. Hence, the production technology in Equation 4.8 enables analysis of both homogenous and non-homogenous products.

Let the index $j \in \mathcal{J} = \{1, 2, \dots, n-1\}$ run across the $n-1$ imported intermediates with trade restrictions. Since CES production is weakly separable, I let the n th imported intermediate, x_n , represent an aggregate intermediate of all the intermediate goods that are traded freely. The expenditure function Equation 4.7 in the CES economy with barriers to trade can then be written

$$\begin{aligned} c_t(p_t, u_t) &= \min_{x_t} \left\{ p'_t x_t : u_t = \left(\sum_{i=1}^n \delta_i x_{it}^\rho \right)^{1/\rho}, x_{jt} = \bar{x}_{jt} < x_{jt}^* \text{ for } j \in \mathcal{J} \right\} \\ &= \sum_{j \in \mathcal{J}} p_{jt} x_{jt} + \frac{p_{nt}}{\delta_n} \left(u_t^\rho - \sum_{j \in \mathcal{J}} \delta_j x_{jt}^\rho \right)^{1/\rho}. \end{aligned} \quad (4.9)$$

x_{jt}^* denotes the optimal level of imports of good j when there are no barriers to trade, i.e., the cost minimising level of imports of good j in Equation 4.4. Since the first $n-1$ intermediate goods are characterised by binding trade restrictions, the second equality follows from substituting the production technology for the n th good in the budget constraint. Utilising that $y_{t-1} = c_{t-1}(p_{t-1}, u_{t-1})$, we can write the import price index

Equation 4.6 in the CES economy as a function of observed prices, quantities and income

$$I_t^{CES} = \left(\sum_{j \in \mathcal{J}} p_{jt} x_{jt} + p_{nt} \left(x_{nt-1}^\rho - \sum_{j \in \mathcal{J}} (\delta_j / \delta_n) (x_{jt}^\rho - x_{jt-1}^\rho) \right)^{1/\rho} \right) / y_{t-1}, \quad (4.10)$$

where the numerator is Equation 4.9, evaluated at u_{t-1} .²¹ To clarify concepts further, I follow how Diewert (1998, p. 51) defined the outlet substitution bias and define the import price bias due to trade barriers (B_t^{CES}) as the difference between the true index (I_t^{CES}) and the Laspeyres index (I_t^L)²²

$$B_t^{CES} \equiv I_t^{CES} - I_t^L. \quad (4.11)$$

The case of perfect substitutes ($\rho = 1$) is of particular interest, for three reasons: it encompasses the case of homogenous products, the bias has an intuitive interpretation, and the case of perfect substitutes will normally represent an upper bound to the true index (I_t^{CES}). It follows from Equation 4.10 that the index when goods are perfect substitutes (I_t^{PS}) is given by:²³

$$I_t^{PS} = I_t^L + \sum_{j \in \mathcal{J}} B_{jt}^{PS}, \quad (4.12)$$

where the good specific bias (B_{jt}^{PS}) is given by²⁴

$$B_{jt}^{PS} = \frac{(p_{jt} - (\delta_j / \delta_n) p_{nt})}{y_{t-1}} \Delta x_{jt}. \quad (4.13)$$

The numerator represents the quality adjusted price difference between the low cost and the high cost intermediate good. When goods are homogenous ($\delta_j / \delta_n = 1$) the numerator represents the absolute price difference between the low cost and the high cost intermediate good. The whole fraction represents the (quality adjusted) amount saved per unit of the low cost good with respect to the cost level in the previous period. In total, the bias when goods are perfect substitutes is defined as the (quality adjusted) amount saved from the new availability of low cost goods relative to the cost level

²¹That is, $u_{t-1}^\rho = \sum_i \delta_i x_{i,t-1}^\rho$ is inserted for u_t^ρ in Equation 4.9. It is assumed that changes in \bar{x}_{jt} are such that $x_{n,t-1}^\rho - \sum_{j \in \mathcal{J}} (\delta_j / \delta_n) (x_{jt}^\rho - x_{jt-1}^\rho) > 0$.

²²The Laspeyres index is defined as $I_t^L \equiv (\sum_i p_{it} x_{it-1}) / (\sum_i p_{it-1} x_{it-1}) = \sum_i s_{it-1} (p_{it} / p_{it-1})$ for $i \in \mathcal{J} \cup \{n\}$.

²³See the appendix, Section C.1

²⁴Equation 4.13 cannot be used directly to calculate the bias when comparing aggregates and not price levels of specific goods. For a given spatial index, (p_{jt} / p_{nt}) , and temporal indices, (p_{jt} / p_{jt-1}) and (x_{jt} / x_{jt-1}) , the bias can be written in a more usable form:

$$B_{jt}^{PS} = ((p_{jt} / p_{jt-1}) - (\delta_j / \delta_n) (p_{jt} / p_{nt}) (p_{jt} / p_{jt-1})) (x_{jt} / x_{jt-1} - 1) s_{jt-1},$$

where s_{jt-1} is the cost share of good j in period $t - 1$.

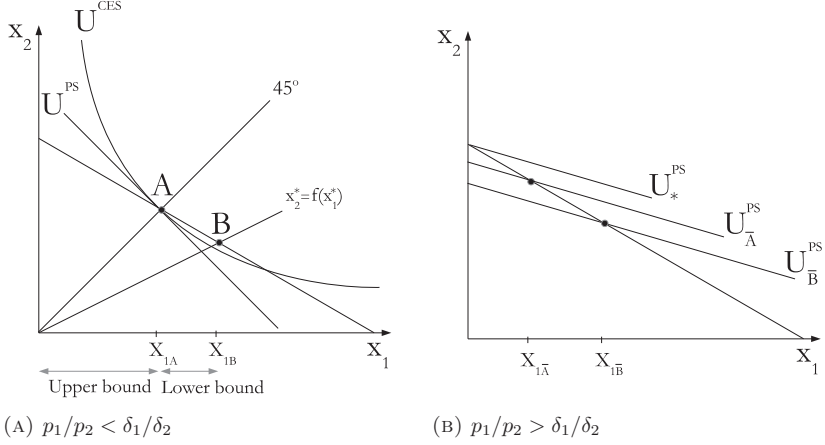


FIGURE 4.2: Trade barrier bias – perfect substitutes as an upper bound: $I_t^{PS} - I_t^{CES} > 0$.

in the previous period. For example, consider the case of two homogenous products ($n = 2$, $\delta_1 = \delta_2$) and assume that prices do not change between two consecutive time periods. The Laspeyres index is then unity. If the total budget is $y_{t-1} = 500$, the price difference between the goods is $p_{1t} - p_{2t} = -10$, and five more low cost goods are purchased ($\Delta x_{1t} = 5$), the bias is $B_{1t}^{PS} = -0.1$. The true index is in this case $I_t^{PS} = 0.9$.

The purpose of the following is to establish conditions when the index I_t^{PS} and the bias $\sum_{j \in \mathcal{J}} B_{jt}^{PS}$ represents a conservative approach to identifying the true index I_t^{CES} and the bias B_t^{CES} . The index I_t^{PS} is said to represent an *upper bound* to the true index I_t^{CES} if $I_t^{PS} - I_t^{CES} > 0$. To provide some intuition, it is appropriate to first consider the case when $n = 2$:

Proposition 4.1. (*Upper bound, $n = 2$*) Consider the import price index Equation 4.10 when $n = 2$. Let the lowering of trade barriers be small, i.e., $x_{1,t} = \epsilon_1 x_{1,t-1}$ where ϵ_1 is greater than, but close to unity, and let TRS_{1t}^{CES} denote the technical rate of substitution of the CES production technology: $TRS_{1t}^{CES} \equiv \frac{\delta_1}{\delta_2} \frac{x_{1t}^{\rho-1}}{x_{2t}^{\rho-1}}$. The index I_t^{PS} represents an upper bound to the true index I_t^{CES} if, and only if

$$TRS_{1t-1}^{CES} > TRS_{1t-1}^{PS}. \quad (4.14)$$

Proof: See the appendix, Section C.2.

It follows from Proposition 4.1 that the index I_t^{PS} represents an upper bound to the true index I_t^{CES} only if $x_{1t-1} < x_{2t-1}$. The intuition underlying this result is illustrated in Figure 4.2a. In this static presentation, it is assumed that prices and costs are unchanged between the two periods. U^{CES} shows the isoquant for a CES production technology and

the line U^{PS} represents the isoquant when the intermediate goods are perfect substitutes. Both isoquants intersect the budget line at point A . When availability is restricted beyond this point, i.e., $x_1 < x_{1A}$, the technical rate of substitution for U^{CES} is higher than for U^{PS} : $TRS^{CES} > TRS^{PS}$. An establishment with technology U^{CES} is willing to give up more units of x_2 in exchange for a unit of x_1 , compared with an establishment with technology U^{PS} . As a result, a lowering of trade barriers leads to a larger increase in production, and a lower cost of imports, when technology is U^{CES} , compared with that of perfect substitutes U^{PS} . The index I^{PS} , which is based on U^{PS} , will thus represent an upper bound to the true index I^{CES} based on technology U^{CES} . When the available amount of x_1 exceeds x_{1A} , the situation changes. The technical rate of substitution for U^{CES} is then lower than the technical rate of substitution for U^{PS} . In this case the index I^{PS} represents a lower bound to the true index I^{CES} . The line going from the origin through point B is the expansion path connecting the optimal import bundles as the cost increases. For CES technology, the expansion path is given by: $x_2^* = f(x_1^*) = \left(\frac{\delta_2 p_1}{\delta_1 p_2}\right)^\sigma x_1^*$. It will be to the right of the 45° degree line if $p_1/p_2 < \delta_1/\delta_2$.

Figure 4.2b illustrates the case when the expansion path is to the left of the 45° degree line, i.e., when x_1 is the high priced good, taking quality into account: $p_1/p_2 > \delta_1/\delta_2$. The isoquant U_*^{PS} shows that it is optimal to only import x_2 . However, if the lowering of trade barriers leads to a movement from $x_{1\bar{A}}$ to $x_{1\bar{B}}$ for the true underlying technology, this will be interpreted as a decrease in the level of production and an increase in cost of imports: the trade barrier bias B_1^{PS} in Equation 4.13 is positive. The index I^{PS} when goods are perfect substitutes is still an upper bound, but for the wrong reasons. Creating an index that serves as an upper bound to the true index when trade barriers are reduced should exclude the case illustrated in Figure 4.2b.

Some adjustments must be made to the index Equation 4.12 to make it an upper bound to the true index in the n good case. As illustrated in Figure 4.2a, the index I^{PS} represents a lower bound if $x_1 > x_{1A}$. To exclude this case, an intuitive approach is to set the good specific bias B_j^{PS} to zero for all goods that lie between x_{1A} and x_{1B} :

Proposition 4.2. (*Upper bound, n*) Consider the import price index Equation 4.10 when $p_{jt-1}/p_{nt-1} < \delta_j/\delta_n$ for $j \in \mathcal{J}$. Let the lowering of trade barriers be small, i.e., $x_{jt} = \epsilon_j x_{jt-1}$ where ϵ_j is greater than, but close to unity. Further, separate the $n-1$ goods that are characterised by trade barriers by dividing the set $\mathcal{J} = \{1, 2, \dots, n-1\}$ into two complement sets $\mathcal{A}_t = \{j \in \mathcal{J} : 0 \leq x_{jt-1} \leq x_{nt-1}\}$ and $\mathcal{A}_t^c = \{j \in \mathcal{J} : x_{nt-1} < x_{jt-1} < x_{jt-1}^*\}$. The import price index

$$I_t^L + \sum_{j \in \mathcal{A}_t} B_{jt}^{PS} \quad (4.15)$$

is an upper bound to the price index I_t^{CES} if $TRS_{j,t-1}^{CES} > p_{jt}/p_{nt}$ for $j \in \mathcal{A}_t^c$, where TRS_{jt}^{CES} denote the technical rate of substitution of the CES production technology: $TRS_{jt}^{CES} \equiv \frac{\delta_j}{\delta_n} \frac{x_{jt}^{\rho-1}}{x_{nt}^{\rho-1}}$. Proof: See the appendix, Section C.3.

The condition in Proposition 4.2 is not restrictive and it is far from necessary. Since $x_{jt-1} < x_{jt-1}^*$, the technical rate of substitution is greater than or equal to the price ratio at time $t-1$: $TRS_{j,t-1}^{CES} > p_{j,t-1}/p_{n,t-1}$. The condition will thus hold if $TRS_{j,t-1}^{CES} > TRS_{jt}^{CES}$, which is equivalent to an increase in the relative consumption of the restricted good: $\Delta(x_{jt}/x_{nt}) > 0$. Alternatively, it will hold if the relative price decreases or remains unchanged between the two time periods: $\Delta(p_{jt}/p_{nt}) \leq 0$.²⁵

4.4 Empirical application

The purpose of this section is to illustrate the importance of the trade barrier bias when calculating price indices. To this end I use the case of clothing imports from China to Norway. The data used in this analysis are based on the two digit SITC from the external trade statistics published by Statistics Norway.²⁶ Let x_{1t} represent the amount of imported clothing from China (measured in tonnes), and x_{2t} represent the amount of imported clothing from all other countries and let p_{1t} and p_{2t} be the corresponding unit values. Because these measures of quantity are not adjusted for differences in quality or other characteristics, unit values are considered less reliable than price surveys, see e.g., Silver (2010). For example, the unit values of audiovisual equipment would typically be unreliable since it has decreased in weight at the same time as technological advances has been considerable. For clothing however, where technological advance has been less pronounced, it is assumed that unit values are indicative of movement in trade prices. Figure 4.3 shows how the relative price level (p_{1t}/p_{2t}) and quantity level (x_{1t}/x_{2t}) have developed between 1988 and 2012.²⁷ In 1988, the price level on imported clothing from China was about 40% compared with the price of clothing from other countries. Over the time period, the relative price level has about doubled to 80% in 2012. The relative level of imported goods from China has also increased during this time period, from a level of about 8% in 1988 to 120% in 2012. This massive increase in imports from China,

²⁵ $\Delta(p_{jt}/p_{nt}) \leq 0$ imply that $p_{j,t-1}/p_{n,t-1} \geq p_{jt}/p_{nt}$.

²⁶ Data are taken from the external trade statistics, Table 08809, see <https://www.ssb.no/en/utenriksokonomi>. Only countries with a positive level of imports across the sample are included. In the end, the data set holds 51 countries. On average, these countries account for 96% of the value of clothing imports to Norway.

²⁷ The spatial index is calculated as $p_{1t}/p_{2t} = \sum_{i \in \mathcal{C}} w_{it} (p_{1t}/p_{it})$, where i run across all other countries than China, \mathcal{C} , and the weights are the import shares: $w_{it} = p_{it}x_{it}/(\sum_{i \in \mathcal{C}} p_{it}x_{it})$. The index (x_{1t}/x_{2t}) is calculated residually, from the product rule: $(y_{1t}/y_{2t}) = (p_{1t}/p_{2t})(x_{1t}/x_{2t})$, where $y_{1t} = p_{1t}x_{1t}$ and $y_{2t} = p_{2t}x_{2t}$.

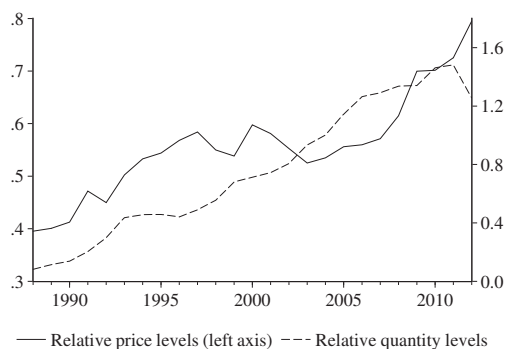


FIGURE 4.3: Imports of clothing: (p_{1t}/p_{2t}) and (x_{1t}/x_{2t})

together with the price surge, begs the question: why has imports from China risen so much when imports from China have become so much more expensive?

Within the standard import price index framework, Figure 4.3 is consistent with clothing produced in China being a Giffen good, i.e., an intermediate that an establishment paradoxically imports more of as the price rises. Another, and more plausible explanation, is that this surge in imports is due to a gradual removal of trade restrictions. After six years of bilateral trade negotiations, Norway rejoined the Multi-Fibre Arrangement (MFA) in 1984. The MFA governed world trade in textiles and garments from 1974 through 2004 by imposing quotas on the amount developing countries could export to developed countries. These quota restrictions came in addition to already high tariff rates, ranging from 17% to 25%. Both quota restrictions and tariffs were gradually reduced during the 1990s and the quota arrangement on clothing expired in 1998 (Wilhelmsen and Høegh-Omdal, 2002). This historical fact tells us that in the first ten years of the sample period, there were indeed restrictions on availability.

Further, and maybe more importantly, the general lowering of trade barriers has led to an increase in supply of clothing from China. At the 8th round of multilateral trade negotiations, known as the Uruguay round, the Agreement on Textiles and Clothing (ATC) ended the MFA and began the process of integrating textile and clothing products into GATT/WTO rules. China entered the WTO on December 11 2001 and on January 1, 2005, the ATC, and all restrictions thereunder, were terminated. This led to a surge in Chinese exports and lower prices of textile and clothing. Harrigan and Barrows (2009) show that the prices of quota constrained categories in the U.S. fell by 38 % in 2005. Moreover, as shown by Brambilla et al. (2010), China's share of U.S. imports jumped threefold, from 10 to 33 %, between the time it joined the WTO and the end of the ATC regime. Consistent with a terms-of-trade effect, most of this growth was in existing

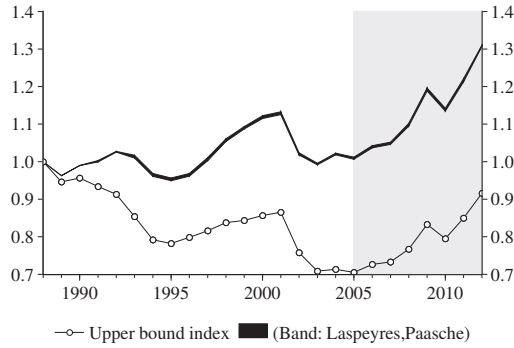


FIGURE 4.4: Cost of imports. The upper bound index follows from Proposition 4.2 and equals $I_t^L + B_{1t}^{PS}$ before 2005 and since $x_{1t-1} > x_{2t-1}$ for $t \geq 2005$, it equals I_t^L after 2005, where the good specific bias is defined by $B_{1t}^{PS} = \frac{(p_{1t} - (\delta_1/\delta_2)p_{2t})}{y_{t-1}} \Delta x_{1t}$ and $\delta_1/\delta_2 = 1$ is set to unity.

varieties (the intensive margin). In line with these findings, Figure 4.3 shows that the relative demand for Chinese clothing continued to increase also in Norway after China joined the WTO.

These historical restrictions on trade in the textile industry, together with the massive increase in imports from China, support the hypothesis that imports of clothing from China has been less than under a free trade regime.

Figure 4.4 shows the development in the import price index with trade barriers compared with the Laspeyres–Paasche band. It is well known that the true import price index lies within the Laspeyres–Paasche band when preferences are homothetic and when there are no barriers to trade, see e.g., the Export and Import Price Index Manual (ILO et al., 2009, p. 421). The difference between the true economic import price index and either the Laspeyres or Paasche index represents a substitution bias, i.e., the bias from not taking account of how importers switch away from goods that have become relatively more expensive and toward goods that have become relatively less expensive. By comparing the trade barrier bias with the Laspeyres–Paasche band yields a visual picture of its importance with respect to the substitution bias.

If the increase in imports from China is caused by substitution and income effects, and there have been no restrictions on availability during this time period, the standard import price framework in Equation 4.4 and Equation 4.5 is valid, and the true index lies somewhere within the Laspeyres–Paasche band. The Laspeyres–Paasche band shows that the standard import price index was about at the same level in 2005 as in 1988, and it was about 30% higher in 2012 than in 1988.

On the other hand, if the increase in imports is a result of increased availability due to lowering of trade barriers and an increase in supply, the import price index with trade barriers (Upper bound index) in Proposition 4.2 should be applied. From the conditions of Proposition 4.2, the goods specific bias (B_{jt}^{PS}) is only subtracted from the Laspeyres index if $x_{1t-1} < x_{2t-1}$. This does not mean that the trade barrier bias is not present when $x_{1t-1} > x_{2t-1}$. From Figure 4.2a and Proposition 4.2 it follows that the trade barrier bias is also present when $x_{1A} < x_1 < x_{1B}$, but the index I_t^{PS} no longer constitutes an upper bound. In Figure 4.3 it can be seen that the case of perfect substitutes is an upper bound until $t = 2005$. The shaded area in Figure 4.4 marks the part of the sample when this condition do not hold. From 2005 to 2012 the upper bound index is the Laspeyres index. It is therefore in the period prior to 2005 that the discrepancy between the Laspeyres–Paasche band and the band of the upper bound index occurs. In 2005, the upper bound index Equation 4.15 is 70% of the Laspeyres index. This amount to a mean annual inflation rate bias between of 1.5 percentage points between 1988 and 2005.

In Figure 4.5 the upper bound index Equation 4.15 is compared with average prices. The average price with quantity shares as weights, commonly referred to as unit values, is used by many statistical bureaus to compare homogenous commodities across different countries of origin in the creation of import price indices, see Chapter 2 in the Export and Import Price Index Manual Manual (ILO et al., 2009). The rationale is that unit values are thought to be appropriate when goods are homogenous: "unit values indices are suitable – indeed they are ideal – for the aggregation of price changes of homogenous items" (ILO et al., 2009, Section B1, 1.10). The use of unit values when there is price variation for the same quality of good or service is also recommended in the SNA 2008 (European Commission et al., 2009, Paragraph 15.68). Average prices and geometric average prices, both using value shares as weights, have been used in the literature to analyse the impact on inflation from a gradual lowering of trade barriers, see e.g., Nickell (2005); Kamin et al. (2006); Pain et al. (2006); Benedictow and Boug (2013). What is striking about this comparison is that the average prices all lie above the upper bound index. Since the true import price index, for any value of the elasticity of substitution σ , lies below the upper bound index, an alternative measure of the impact of trade liberalisation on import prices should, at a minimum, also lie below the upper bound index. That the average prices lie above the upper bound index illustrates how average prices is not a measure of cost of imports effects from trade liberalisation. The mean inflation rate between 1988 and 2005 of the average price index was -1.1%, the mean inflation rate of the geometric average price was -1.3% and the mean inflation rate of the unit value index was -1.4%. In contrast, the mean inflation rate of the upper bound index was -1.9%. In other words, the annual underestimation of how trade liberalisation

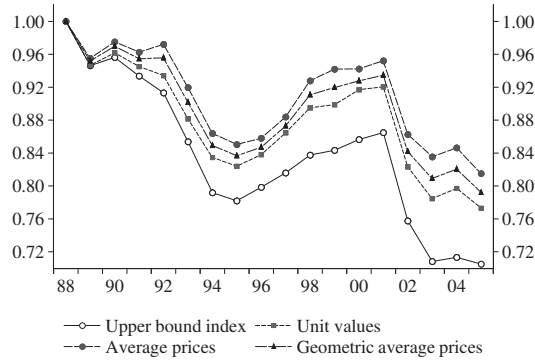


FIGURE 4.5: The upper bound index vs. average prices. The upper bound index is Equation 4.15 given in Proposition 4.2, using $\delta_1/\delta_2 = 1$. Unit values, average prices and geometric average prices are chained from p_t/p_{t-1} , where the price levels are defined by $p_t = \left(\frac{x_{1t}}{x_{1t}+x_{2t}}\right)p_{1t} + \left(\frac{x_{2t}}{x_{1t}+x_{2t}}\right)p_{2t}$, $p_t = s_{1t}p_{1t} + (1-s_{1t})p_{2t}$ and $\ln p_t = s_{1t} \ln p_{1t} + (1-s_{1t}) \ln p_{2t}$, c.f. Equation 4.2, respectively.

has affected inflation from using average prices, geometric average prices and unit values was at least 0.8, 0.6 and 0.5 percentage points respectively. When trade barriers are present, the use of unit values to aggregate homogenous items can thus yield biased results.

4.5 Conclusions

Applying a standard import price index to situations with trade barriers yields biased results since the standard index implicitly assumes free trade. The literature analysing how a gradual lowering of trade barriers and an increased integration of low cost countries into the world economy have put downward pressure on inflation rates try to circumvent this problem by looking at average prices. However, average prices may still underestimate the economic effects from trade liberalisation.

The purpose of this chapter has been twofold. The first aim was to generalise the original economic import price index to allow for barriers to trade in the case of homogenous products. The second aim has been to establish under what conditions this index serves as a conservative measure to the true index also in the case of non-homogenous goods. Hence, the results of this chapter can be used to calculate conservative estimates of cost reductions due to trade liberalisation both in the case of homogeneous and non-homogenous goods. To illustrate the theoretical framework, I use the case of clothing

imports to Norway and show that a unit value index, which is believed to be appropriate for the aggregation of homogenous items, overestimated the annual inflation rate by 0.5 percentage points between 1988 and 2005.

Chapter 5

Identifying the sector bias of technical change

Abstract: The empirical literature studying the sector bias of technical change has only focused on skill-biased technical change. In this chapter, I analyse the sector bias of *both* factor-neutral and factor-biased technical change. The empirical evidence using Norwegian data from 1972 to 2007 is not clear on the impact of a sector bias of skill-biased technical change, but it points to a sector bias of factor-neutral technical change from the 1970s to the 1990s. That said, the impact of the sector bias seems to have reduced towards the latter part of the sample period. I also evaluate the cross-section model used in the literature and show the strong restrictions that must be placed on a vector equilibrium correction model to end up with the standard model. If these restrictions do not hold, the results reported in the literature may be biased. I show that the restrictions are strongly rejected, and that erroneously imposing them significantly changes the estimates of skill-biased technical change in many sectors. These results can, to some extent, be traced back to how the cross-section model ignores initial disequilibrium and imposes factors of production to be either complements or substitutes.

5.1 Introduction

In the past three decades, most OECD countries have experienced an increase in the wage premium and/or an increase in the relative unemployment rates between high- and low-skilled labour. The underlying reasons for this development are still debated (Acemoglu and Autor, 2011). A growing body of research points to increased international trade, capital-skill complementarity or a shift in the production technology that favours skilled over unskilled.

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In the literature on skill-biased technical change (henceforth SBTC) there is an ongoing debate concerning the importance of a sector bias of SBTC. While the SBTC hypothesis is based on the relative profitability between factors of production, the sector bias hypothesis focuses on the relative profitability between sectors. For example, if the proportion of high-skilled labour varies across sectors, it is not clear that skill-biased technical change will lead to a higher wage premium. If technical change favours skilled labour in a sector where the proportion of skilled labour is low, this will increase the profitability of the sector where technical change takes place. Even if technical change were directed at the high-skilled, because technical change took place in a sector dominated by low-skilled labour, this would lead to an increase in demand of low-skilled labour and consequently a lowering of the wage premium. In other words, the skill intensity of the sector where technical change occurs matters for the development of the wage premium. This theoretical result is well known and dates back to at least Findlay and Grubert (1959).

Econometric studies have found the sector bias hypothesis to be important in understanding the development of the wage premium. In line with the sector bias hypothesis, Haskel and Slaughter (2002) find that in a group of 10 OECD countries where the wage premia were rising (falling) during the 1970s and 80s, SBTC was generally concentrated in skill-intensive (unskill-intensive) sectors. Applying a similar econometric framework, Esposito and Stehrer (2009) also find the sector bias hypothesis to be important in explaining the rising wage premia in the Czech Republic, Hungary, and Poland during the late nineties. In contrast, Robertson (2004) finds that a weakly significant sector bias has worked in the opposite direction, as would be expected if it was to explain changes in wage inequality in Mexico during the period of trade liberalisation from 1986 to 1999.

The econometric framework typically used in the literature to identify SBTC is based on a panel version of the *growth rate econometric model* (Hendry, 1995, Section 7.4), henceforth referred to as the cross-section model. This approach implicitly assumes that a number of restrictions are satisfied. For example, it is assumed that initial disequilibrium is irrelevant to the identification of structural parameters. The model also imposes factors of production to be either complements or substitutes. If these implicit restrictions do not hold, the estimates reported in the literature may be biased.

In this chapter, I present a more general econometric framework. Using a vector equilibrium correction model (henceforth VEqCM), I show how to identify SBTC without imposing the strong restrictions implicitly used in the literature. To relate this framework to existing studies, I list a set of testable assumptions that must be imposed on the VEqCM in order to identify SBTC with the cross-section model. The restrictions that must be placed on the VEqCM to end up with the cross-section model are strongly

rejected using Norwegian data from 1972 to 2007. Imposing them significantly changes the estimates of SBTC. This result can, to some extent, be traced back to how the cross-section model ignores initial disequilibrium and imposes the assumption that factors of production are either complements or substitutes.

The empirical literature analysing a sector bias of technical change has not, to my knowledge, analysed the impact from factor-neutral technical change or total factor productivity growth (TFP). A sector bias of TFP is present if there is a systematic relationship between TFP growth and skill intensity across sectors. From a theoretical standpoint, it should be easier to identify the sector bias of TFP than the sector bias of SBTC, since it is independent of the elasticity of substitution between the factors of production; see Stehrer (2010, p. 75). Although insignificant, the empirical evidence in this chapter points to a sector bias of TFP in the 1970s, but that the impact of the sector bias gradually reduced towards the first decade in the current century.

The rest of the chapter is organised as follows: Section 5.2 reviews the theoretical literature on the sector bias of technical change. Section 5.3 evaluates the empirical framework used in the literature and outlines how to identify the sector bias of both SBTC and TFP. Section 5.4 describes the data set used in the empirical analysis. Section 5.5 reports and discusses the empirical results. Section 5.6 concludes.

5.2 The sector bias of technical change

The sector bias hypothesis focuses on the relative profitability between sectors. For example, if technical change favours skilled labour in a sector where the proportion of skilled labour is low, this will increase the profitability of the sector where technical change takes place. Even if technical change were directed at the high-skilled, this would lead to an increase in demand for low-skilled labour and may consequently lead to a lowering of the wage premium. This result, that the skill intensity of the sector where technical change occurs matters for the development of the wage premium, was the basis for the analysis by Haskel and Slaughter (2002).

The extent to which the sector bias impacts factor prices depends on the properties of the economy under consideration. Xu (2001) analysed how different forms of technical change impact relative factor prices in a two-country, two-good, two-factor Heckscher-Ohlin model. Some of the results were ambiguous. Stehrer (2010) shed light on this ambiguity. In a more detailed study, he analysed the effects of technical change on relative wages for various combinations of parameter values in an economy characterised by CES utility and production functions. Of particular importance is the elasticity of

substitution in demand and in production. Since the model in Stehrer (2010) holds a discrete number of sectors the elasticity of substitution in production can be assumed to be sector-specific. Stehrer (2010) assumes endogenous product prices both when considering a closed economy and when extending the framework to a discrete number of trading economies. Consequently, in the case of trading economies, the law of one price does not hold, since each good is considered a specific brand. Haskel and Slaughter (2002) also considers the case when product prices are endogenous, but in contrast to Stehrer (2010), the main assumption is not the specificity of brands, but rather that the country under consideration is sufficiently large in the world economy to affect product prices.

Stehrer (2010) showed that the size and the direction of the sector bias depend on the size of the elasticity of substitution. When factors of production are substitutes, SBTC increases the wage premium if the innovating sector is not too skill intensive.²⁸ When SBTC occurs in a very skill-intensive sector, the demand for goods in the unskill-intensive sectors rises due to a dominating income effect which moreover causes a reduction in the relative wage rate. If, on the other hand, the factors of production are complements, the impact of SBTC on the wage premium becomes ambiguous (Stehrer, 2010, p. 76, footnote 14.). The second case, when the elasticity of substitution in demand is high, is similar. If factors of production are substitutes but the elasticity of substitution in production is lower than the elasticity of substitution in demand, SBTC increases the wage premium for a large range of sectors, unless SBTC occurs in sectors with a very low skill level. In sum, the impact from the sector bias of SBTC depends on the skill intensities where SBTC occurs, whether factors of production are complements or substitutes, and on the elasticity of substitution in demand.

Although the empirical literature has focused on the sector bias of SBTC, Stehrer (2010) also analysed the sector bias of TFP. How TFP impacts the relative wage rate also depends on the elasticity of substitution of demand. If the elasticity of substitution of demand is lower than unity, the relative wage rate will rise if TFP occurs mostly in unskilled sectors. The rising wage premium is due to a dominating income effect which causes increased demand for all goods and in particular for goods produced with high skill intensities. On the other hand, if the elasticity of substitution of demand is greater than unity, the relative wage rate will rise if TFP occurs mostly in skilled sectors. In either case, a sector bias of TFP is thus caused by a systematic relationship between TFP growth and skill intensity across sectors.

²⁸Note that I refer to SBTC only, i.e., skill-biased (skill-using) technical change, which is the Hicksian notion of technical change. Stehrer (2010, Section 2.2) discusses the different typologies of technical change and how they relate to the parameters in a CES production function more explicitly.

5.3 Econometric framework

Since Norway represents a very small open economy, and since the empirical analysis in this chapter also includes services sectors where product prices typically are determined endogenously, the theoretical results from Stehrer (2010) are considered the most relevant for the econometric framework. In particular, the econometric framework takes into account both the skill intensity of sectors and, in the case of skill-biased technical change, the size of the elasticity of substitution between the factors of production. In the following, I first present the cross-section model adopted by Haskel and Slaughter (2002) to identify SBTC and then show how the vector equilibrium correction model encompasses this model. Thereafter, I show the index used to calculate TFP, and finally, I outline how to identify the sector bias of both SBTC and TFP.

5.3.1 Framework used in the literature

Haskel and Slaughter (2002) used a two-stage estimation procedure to identify the sector bias of SBTC. First they regressed the level change in the cost share of high-skilled (S) in sector i on changes in the wage premium, i.e., the ratio of the hourly wage of high-skilled (W_H) and the wage of low-skilled (W_L), and changes in capital intensity (K/Y)

$$\Delta S_i = b_1 + b_2 \Delta \ln(W_H/W_L)_i + b_3 \Delta \ln(K/Y)_i + u_i, \quad (5.1)$$

where K is capital and Y is real value-added output. The wage premium was modelled as the relative wage between production and non-production workers where non-production workers served as a proxy for high-skilled. The variation in the cost share that could not be explained by variation in neither the wage premium nor the capital intensity was attributed to SBTC, i.e., $(b_1 + u_i)$ was a measure of SBTC in sector i . In the second stage, the estimate of SBTC is regressed on the skill intensity

$$SBTC_i = \gamma_1 + \gamma_2 (H/L)_i + v_i, \quad (5.2)$$

where the skill intensity is the ratio of high- (H) to low (L) skilled workers. Haskel and Slaughter (2002) considered the coefficient γ_2 to represent the sector bias of SBTC. They state that if the sector-bias hypothesis is true, then a positive γ_2 is associated with rising skill premia and a negative γ_2 with falling skill premia (p. 1768). In the following two sections, I evaluate the suitability of this framework for analysing the sector bias hypothesis.

5.3.2 Identifying SBTC

Most econometric studies analysing SBTC and a potential sector bias use the translog cost function due to its flexibility and to the fact that it represents a second-order approximation of a general cost function; see for example Berman et al. (1994) and Binswanger (1974). The cost share of high-skilled labour in levels (S) is given by

$$S_{it} = b_{0i} + b_{1i}t + b_{2i} \ln(W_H/W_L)_{it} + b_{3i} \ln(K/Y)_{it}. \quad (5.3)$$

This framework is empirically convenient, since the cost share is a linear function of the wage premium, the capital intensity and a deterministic time trend (t).²⁹ A positive parameter b_{3i} indicates capital-skill complementarity. The parameter b_{1i} represents technical change. For example, if one empirically finds a significant positive value, it means that there has been an exogenous force increasing the relative demand for skilled labour and thus increasing the cost share of skilled labour. SBTC or skill using technical progress therefore occurs within the translog framework when there is a *ceteris paribus* deterministic increase in the cost share of high-skilled labour, i.e., $b_{1i} > 0$. Conversely, a negative value ($b_{1i} < 0$) implies that technical change has been biased towards unskilled labour. Note that even though this model is derived under cost minimisation, any trends in, for example, international product prices or general equilibrium effects that are not related to the wage premium, capital or value-added will empirically be interpreted as SBTC.

The parameter b_{2i} is closely related to the elasticity of substitution. As there are only two variable inputs, the expression for the elasticity of substitution between the two factors is defined by

$$\sigma_i \equiv \frac{\partial \ln(H_i/L_i)}{\partial \ln(W_{Li}/W_{Hi})} = 1 - \frac{b_{2i}}{\hat{S}_i(1 - \hat{S}_i)}, \quad (5.4)$$

where \hat{S}_i is the predicted high-skilled cost share at some central point such as the mean.³⁰ Since there are only two variable factors of production, the elasticity of substitution is non-negative, i.e., an increase in $\ln(W_{Li}/W_{Hi})$ (a lowering of the wage premium) is met by either an increase in the skill ratio (H_i/L_i) or a constant skill ratio. Importantly, a positive estimate of b_{2i} implies an elasticity of substitution lower than unity, and a negative estimate of b_{2i} implies an elasticity of substitution greater than unity.

²⁹ Both constant returns to scale and price homogeneity have been imposed; see the appendix, Section D.1.

³⁰ In contrast, several measures of the elasticity of substitution have been discussed in the literature when there are many inputs; see for example Blackorby and Russel (1989) and Thompson (1997).

The vector equilibrium correction (VEqCM) model can be used to identify the parameters of the theoretical cost share Equation 5.3. The point of departure is the general model

$$(\text{VEqCM}) \quad \Delta \mathbf{x}_{i,t} = \tilde{\gamma}_i + \Gamma_{1i} \Delta \mathbf{x}_{i,t-1} + \cdots + \Gamma_{ki} \Delta \mathbf{x}_{i,t-k} + \Pi_i \tilde{\mathbf{x}}_{i,t-1} + \epsilon_{it},$$

where I allow for both a constant and a trend within the potential cointegrating relationships by defining the (3×1) vector $\mathbf{x}'_{it} = [S \ \ln(W_H/W_L) \ \ln(K/Y)]_{it}$ and the (5×1) vector $\tilde{\mathbf{x}}'_{it} = [\mathbf{x}'_{it} \ t \ 1]$. The model allows for the possibility of a linear trend in all the components of \mathbf{x}_{it} , as captured by the vector of constants $\tilde{\gamma}_i$. The fact that there must be a mapping between these trends and the trend in the cointegrating relations can be used to identify the constants in the cointegration relationships, see e.g., Hungnes (2010). Although the model is specified with a stable deterministic trend, the methods outlined in Johansen et al. (2000) and Hungnes (2010) can be used to identify possible structural breaks. ϵ_{it} is assumed multivariate normally distributed with covariance matrix Ω . The (3×5) matrix Π can be partitioned into $\Pi = \alpha \beta'$ where the $(3 \times r)$ matrix α represents the speed of adjustment to disequilibrium, β' is the $(r \times 5)$ matrix of long-run coefficients and where r represents the number of cointegration relationships. If there is one cointegration relationship only ($r = 1$), the matrix Π can be partitioned to identify the long-run structure in the translog model in Equation 5.3, that is

$$\Pi_i = \alpha_i \beta'_i = \begin{bmatrix} \alpha_{1i} \\ \alpha_{2i} \\ \alpha_{3i} \end{bmatrix} \begin{bmatrix} 1 & -b_2 & -b_3 & -b_1 & -b_0 \end{bmatrix}_i.$$

The VEqCM is somewhat different from the framework used in the literature, for example Haskel and Slaughter (2002). In particular, the VEqCM can be viewed as a more general model. In the following I list the set of testable assumptions that must be imposed on the VEqCM in order to end up with the framework used by Haskel and Slaughter (2002).

Assumption 1. *The wage premium and capital intensity are weakly exogenous, i.e., $\alpha_{2i} = \alpha_{3i} = 0$*

The weak exogeneity assumption implies that it is the cost share variable alone that adjusts towards the equilibrium relationship. If true, this assumption allows for single equation modelling. More specifically, the conditional process for the cost share is then given by

$$(A1) \quad \Delta S_{it} = \gamma_i + \omega_{1i} \Delta \ln(W_H/W_L)_{it} + \omega_{2i} \Delta \ln(K/Y)_{it} \\ + \alpha_{1i} \beta'_i \tilde{\mathbf{x}}_{i,t-1} + \sum_{j=1}^k \tilde{\Gamma}_{ji} \Delta \mathbf{x}_{it-j} + \epsilon_{1it},$$

where the subscript on the residual ϵ_{1it} refers to the assumption under which it is constructed. The relationships between γ_i , ω_{1i} , ω_{2i} , $\tilde{\Gamma}_{j,i}$ and ϵ_{1it} in model A1 and the parameters in the VEqCM model are shown in Johansen (1995, p. 122). If the weak exogeneity assumption is wrongly imposed, the estimate of the long-run parameter β_i will be inefficient (Johansen, 1992).

Assumption 2. *There are no significant lags in the VEqCM, i.e., $\tilde{\Gamma}_{ji} = \mathbf{0} \quad \forall i, j$*

If there are no significant lags in A1, the model is reduced to the specification

$$(A2) \quad \Delta S_{it} = \gamma_i + \omega_{1i} \Delta \ln(W_H/W_L)_{it} + \omega_{2i} \Delta \ln(K/Y)_{it} + \alpha_{1i} \beta'_i \tilde{\mathbf{x}}_{it-1} + \epsilon_{2it}.$$

This model is more efficient than A1 if Assumption 2 holds, since no unnecessary coefficients are estimated. However, if Assumption 2 is wrongly imposed, the error term is serially dependant and the estimate of the long-run parameter β_i will be biased. Inference on skill-biased technical change is no longer valid.

Assumption 3. *There is no adjustment towards equilibrium, i.e., $\alpha_{1i} = 0$.*

Assumption 3 leads to the specification commonly referred to as a cross-section model

$$(A3) \quad \Delta S_{it} = \gamma_i + \omega_{1i} \Delta \ln(W_H/W_L)_{it} + \omega_{2i} \Delta \ln(K/Y)_{it} + \epsilon_{3it}.$$

In the models VEqCM, A1, and A2 the structural parameters of the translog framework have been a part of the vector β'_i , but in Model A3 the vector β'_i is not included. In this model the structural parameters can be found by taking the first difference of the translog framework (5.3),

$$(A3) \quad \Delta S_{it} = b_{1i} + b_{2i} \Delta \ln(W_H/W_L)_{it} + b_{3i} \Delta \ln(K/Y)_{it} + \epsilon_{3it},$$

which yield the relationships $b_{1i} = \gamma_i$, $b_{2i} = \omega_{1i}$ and $b_{3i} = \omega_{2i}$. Given that Assumptions 1–3 are all true, the OLS estimate of SBTC ($b_{1,i}$) is unbiased and efficient. However, for given time paths of $\Delta \ln(W_H/W_L)_{it}$ and $\Delta \ln(K/Y)_{it}$, the time path of ΔS_{it} , may depend on the relationship between the initial levels of the cost share (S_{0t}), the wage premium ($\ln(W_H/W_L)_{i0}$), and capital intensity ($\ln(K/Y)_{i0}$). There are no a priori grounds

for assuming that such an initial disequilibrium is irrelevant. If the assumption of no equilibrium correction is false and – in particular – if there is a large deviation from equilibrium initially, estimates of SBTC will be biased.³¹

Assumption 4. *Homogeneous slope parameters across sectors, i.e., $b_{2i} = b_2$ and $b_{3i} = b_3$.*

The assumption that the slope parameters are homogeneous across sectors yields the *fixed effects* model

$$(A4) \quad \Delta S_{it} = b_{1,i} + b_2 \Delta \ln(W_H/W_L)_{it} + b_3 \Delta \ln(K/Y)_{it} + \epsilon_{4it},$$

In this framework, sector-specific SBTC is still identified by the sector-specific constant b_{1i} . If Assumptions 2–4 are all true, the estimates of the slope parameters are more efficient than the OLS estimates of A3, since fewer parameters are estimated and information across sectors is also utilised. By denoting the estimators of SBTC in A3 and A4 by \hat{b}_{1i}^{A3} and \hat{b}_{1i}^{A4} respectively, the difference between these estimators can be decomposed into separate effects from the two explanatory variables as

$$\hat{b}_{1i}^{A3} - \hat{b}_{1i}^{A4} = (\hat{b}_2 - \hat{b}_{2i}) \overline{\Delta \ln(W_H/W_L)_i} + (\hat{b}_3 - \hat{b}_{3i}) \overline{\Delta \ln(K/Y)_i}. \quad (5.5)$$

If Assumption 4 is wrongly imposed, the estimates of the slope parameters in a given sector will be biased, and this bias leads to wrongful inference of SBTC unless the two effects precisely offset each other. Moreover, by imposing homogeneous slope parameters across sectors, one is restricting the elasticity of substitution between the factors of production to be of the same type. From equation (5.4) it follows that even though the elasticity of substitution can vary between sectors with a common slope parameter, $\sigma_i = 1 - \frac{b_2}{S_i(1-S_i)}$, the elasticity of substitution is either above or below unity depending on whether b_2 is positive or negative. Since unity marks a threshold for the elasticity of substitution in terms of how SBTC impacts the wage premium (Stehrer, 2010), imposing that factors of production are *either* substitutes or complements can lead to wrongful inference about the sector bias.

Assumption 5. *No sector-specific heterogeneity, i.e., $b_{1i} = b_1$.*

Assumption 5 leads to a specification without sector-specific heterogeneity, i.e., where both the slope coefficients and the intercept are the same for all sectors

$$(A5) \quad \Delta S_{it} = b_1 + b_2 \Delta \ln(W_H/W_L)_{it} + b_3 \Delta \ln(K/Y)_{it} + \epsilon_{5it}.$$

³¹See Hendry (1995, Section 7.4) for further discussion of the cross-section model.

The estimator for the slope coefficients is often referred to as a *global estimator* since it utilises both the variation within and between sectors. It is this framework Esposito and Stehrer (2009) used when identifying a sector bias in three central and eastern European transition economies. According to Esposito and Stehrer (2009), b_1 measures the cross-sector average of SBTC whereas $(b_1 + \epsilon_{5it})$ reflects the sectoral distribution of SBTC (p. 358). But the reason why b_1 measures the cross-sector average of SBTC is due to Assumption 5 where it is explicitly stated that there is no cross-sector variation in SBTC. Defining a new variable $b_1 + \epsilon_{5it}$ to capture cross-sectoral distribution of SBTC is inconsistent with the assumption that there is no heterogeneity in SBTC.

If one incorrectly imposes Assumption 5, there will be a double bias in the estimation of SBTC. To see this, rewrite the fixed-effects model A4 as

$$\Delta S_{it} = b_1 + b_2 \Delta \ln(W_H/W_L)_{it} + b_3 \Delta \ln(K/Y)_{it} + (b_{1i} - b_1 + \epsilon_{4it}),$$

where it follows from A5 that $\epsilon_{5it} = b_{1,i} - b_1 + \epsilon_{4it}$. The sectoral distribution of SBTC, as defined by Esposito and Stehrer (2009), is then given by $b_1 + \epsilon_{5it} = b_{1i} + \epsilon_{4it}$. First, all of the random noise captured in the data that is included in the residual ϵ_{4it} will in this model be interpreted as sector-specific SBTC. Second, unless there is no correlation between the regressors and the sector-specific means (b_{1i}), the estimator for b_2 , b_3 and most importantly b_1 will be biased. Consequently, the estimator for sector-specific SBTC is also biased. In other words, if one really believes that the intercepts vary across sectors, one should stick to modelling the fixed-effects equation (A4) where such heterogeneity is explicitly allowed for.

Assumption 6. *Estimating the multiperiod difference:*³² $\Delta S_{iT} = S_{iT} - S_{i0}$

For the purpose of identifying sector-specific SBTC, Haskel and Slaughter (2002) and Robertson (2004) used the cross-sectoral model

$$(A6) \quad \Delta S_{iT} = b_1 + b_2 \Delta \ln(W_H/W_L)_{iT} + b_3 \Delta \ln(K/Y)_{iT} + \epsilon_{6iT}, \quad (5.6)$$

where for example ΔS_{iT} represents the multiperiod difference $\Delta S_{iT} = S_{iT} - S_{i0}$. In this model, $T^{-1}(b_1 + \epsilon_{6iT})$ is viewed as the sectoral distribution of SBTC. Identifying sectoral distribution of SBTC in this way was also done by, for example, Berman et al. (1994). However, the inconsistency of identifying sector-specific parameters in a model where all parameters are homogeneous still applies to this model. The use of A6 in the literature is therefore probably due to lack of proper panel data and not because it is a

³²Even though the multiperiod difference represents a new type of model, and not an assumption that can be tested empirically, I list it as an assumption since this framework is linked to the more general framework A4, as this section will show.

preferred econometric model when panel data is readily available. This point becomes clearer when comparing the estimator for the slope coefficients in A4 with the estimator for the slope coefficients in A6. To this end, note that the multiperiod difference can be written

$$\Delta S_{iT} = S_{iT} - S_{i0} = (S_{iT} - S_{iT-1}) + (S_{iT-1} - S_{iT-2}) + \cdots + (S_{i1} - S_{i0}) = \sum_t \Delta S_{it}.$$

In other words, the model A6 is an equation in sector-specific means and the estimator of the slope coefficients is typically referred to as the *between estimator*. In contrast, the estimator for the slope coefficients in the fixed-effects model A4 is commonly referred to as the *within estimator*. Given that A4 is the preferred econometric model and that A6 is used due to lack of time series data, it would be favourable in terms of identification if there were a connection between the two estimators. However, there is no connection, as the two estimators are uncorrelated; see for example Arellano (2002, p.36). Even if Assumption 5 holds and there is no sector-specific heterogeneity, estimating the slope parameters with the between estimator in A6 instead of the global estimator in A5 is inefficient. The econometric model A6 should therefore not be used to identify sector-specific SBTC when panel data are available.

5.3.3 Identifying TFP growth

Total factor productivity growth is calculated using the Törnqvist productivity index

$$\Delta \ln TFP_{it} = \Delta \ln Y_{it} - \overline{s_{Hit}} \Delta \ln H_{it} - \overline{s_{Lit}} \Delta \ln L_{it} - \overline{s_{Kit}} \Delta \ln K_{it}, \quad (5.7)$$

where Y_{it} is value-added in sector i at time t , s_{jit} is the factor share of factor $j = H, L, K$ computed with regard to value-added in current prices. An overline above a variable indicates the moving average operator, in this case between two time periods, i.e., $\overline{s_{Hit}} = 1/2(s_{Hit} + s_{Hit-1})$. This index is exact for a translog production function and is commonly used to identify TFP growth; see for example OECD (2001).

5.3.4 Identifying a sector bias of SBTC

The second stage of identifying a sector bias of SBTC is to regress the estimate of SBTC in the first stage on the level of skill intensity in Equation 5.2. In Stehrer (2010), it was shown that the impact of the sector bias depends on the type of substitution between high- and low-skilled labour in a sector. Since an elasticity of substitution equal to unity marks a threshold value for the sector bias, the second-stage regression

is done separately in the case where factors of production are substitutes ($\sigma_i > 1$) and complements ($\sigma_i < 1$).

5.3.5 Identifying a sector bias of TFP

The results from Stehrer (2010) implied that there is a sector bias of TFP if there is a systematic relationship between TFP growth and skill intensity. To identify a sector bias of TFP, I apply a similar procedure as used in Haskel and Slaughter (2002) to identify the sector bias of SBTC and regress the mean growth in TFP on the skill intensity

$$\overline{\Delta \ln TFP_i} = \phi_1 + \phi_2(H/L)_i + z_i, \quad (5.8)$$

where the overline represents the moving average operator $\overline{\Delta \ln TFP_i} = 1/T \sum \Delta \ln TFP_{it}$. As shown in Stehrer (2010), if the elasticity of substitution of demand is low, the relative wage rate will rise if TFP occurs mostly in unskilled sectors, which is consistent with a significant negative estimate of ϕ_2 . On the other hand, if the elasticity of substitution of demand is high, the relative wage rate will rise if TFP occurs mostly in skilled sectors, which is consistent with a positive estimate of ϕ_2 .

5.4 Data description

In total, the dataset covers 12 private sectors over the period 1972-2007. Data on wages separated into high-skilled and low-skilled and data on employment classified by high-skilled and low-skilled are taken from the Labour Accounts classified by level of education. Low-skilled labour is defined as workers with primary, secondary and/or vocational education only, i.e., less than 13 years of schooling. Workers with 13 years of schooling or more are defined as skilled. The employment figures in the Labour Accounts classified by level of education are based on the Register of Employers and Employees (REE). All employers are obliged to report employment information to the Norwegian Labour and Welfare Administration (NAV) which administers the REE. The REE database, where each person is identified with his or her personal identification number, has been linked with information about educational levels from the Norwegian State Educational Loan Fund (Lånekassen) from 1986 onwards. Prior to 1986, register-based employment figures consistent with the National Accounts were not available. In order to extend the series prior to 1986, data from the Labour Force Survey between 1972 and 1986 are used. Details concerning the creation of employment statistics classified by level of education can be found in Skotner (1994). Wage data are retrieved from the

TABLE 5.1: Descriptive evidence

	Wage premium			Skill intensity			Cost share		
	1972	1986	Δ	1972	1986	Δ	1972	1986	Δ
15 Consumption goods	1.72	1.58	-0.13	0.03	0.05	0.03	0.05	0.08	0.03
25 Misc. manufacturing	1.68	1.49	-0.20	0.06	0.11	0.05	0.09	0.14	0.05
30 Energy intensive manufacturing	1.92	1.78	-0.14	0.08	0.15	0.07	0.13	0.21	0.08
45 Engineering products	1.74	1.61	-0.13	0.14	0.22	0.07	0.20	0.26	0.06
50 Oil platforms and ships	1.90	1.75	-0.15	0.10	0.17	0.07	0.16	0.23	0.07
55 Construction	1.63	1.77	0.14	0.03	0.07	0.04	0.05	0.11	0.06
63 Financial intermediates	1.32	1.31	-0.02	0.25	0.30	0.05	0.25	0.28	0.03
64 Oil and gas exploration	1.63	1.36	-0.28	0.04	0.47	0.43	0.06	0.39	0.33
71 Electricity	1.79	1.62	-0.16	0.16	0.21	0.05	0.23	0.26	0.03
74 Domestic transportation	1.79	1.63	-0.16	0.03	0.07	0.04	0.06	0.11	0.05
81 Wholesale and retail trade	1.94	1.61	-0.33	0.03	0.08	0.05	0.05	0.11	0.06
85 Other private services	1.45	1.37	-0.08	0.33	0.42	0.10	0.32	0.37	0.05
	1987	2007	Δ	1987	2007	Δ	1987	2007	Δ
15 Consumption goods	1.57	1.45	-0.13	0.05	0.11	0.05	0.08	0.14	0.06
25 Misc. manufacturing	1.44	1.39	-0.04	0.12	0.23	0.11	0.14	0.24	0.10
30 Energy intensive manufacturing	1.70	1.57	-0.13	0.16	0.22	0.06	0.21	0.26	0.04
45 Engineering products	1.57	1.48	-0.09	0.22	0.26	0.04	0.26	0.27	0.02
50 Oil platforms and ships	1.72	1.55	-0.17	0.18	0.23	0.04	0.24	0.26	0.02
55 Construction	1.70	1.58	-0.12	0.07	0.07	0.00	0.10	0.10	-0.00
63 Financial intermediates	1.27	1.40	0.13	0.32	0.83	0.51	0.29	0.54	0.25
64 Oil and gas exploration	1.32	1.25	-0.06	0.48	0.61	0.13	0.39	0.43	0.05
71 Electricity	1.63	1.50	-0.12	0.23	0.47	0.24	0.27	0.41	0.14
74 Domestic transportation	1.58	1.57	-0.02	0.07	0.17	0.10	0.10	0.21	0.11
81 Wholesale and retail trade	1.61	1.43	-0.18	0.08	0.16	0.08	0.12	0.19	0.07
85 Other private services	1.36	1.31	-0.05	0.42	0.58	0.15	0.37	0.43	0.06

Definitions: $Wage\ premium = W_H/W_L$, $Skill\ intensity = H/L$ and the high-skilled $Cost\ share\ (S) = W_H H / (W_H H + W_L L)$. Δ shows the difference in levels (in the top part of the table between 1986 and 1972 and in the lower part between 2007 and 1987).

survey-based Wage Statistics.³³ The population for the wage statistics is basically all active establishments in the Central Register of Establishments and Enterprises. All of the largest enterprises are sampled. Among the small- and medium-sized enterprises, the sampling rates are about 40–50 and 10–20 per cent, respectively. In 2007, the Labour Accounts classified by the level of education covered about 60 per cent of all wage earners. In total, this new account system now holds information, consistent with the National Accounts at a two-digit level, concerning employment, hours worked, wages, and payroll costs across wage earners and self-employed, and educational levels.³⁴

³³In 1997, Statistics Norway established a set of uniform and comprehensive wage statistics. The use of national and international standards makes the statistics accessible and comparable to other national and international statistics. Hytjan et al. (2005) and Lien et al. (2009) provide further details regarding the Wage Statistics.

³⁴See Skoglund and Todsén (2007) for details regarding the definitions applied in the Labour Accounts. For example, wages refer to cash remuneration for services rendered, paid by the employer to the employee, while payroll costs include national insurance and pension premiums.

Further information about the most recent Labour Accounts can be found in Gimming (2010).

Value-added and capital figures are taken from the National Accounts.³⁵ Capital may include objects such as buildings, oil and gas pipelines, boats, means of transport, machinery, software, valuables, oil platforms, airplanes and helicopters. The perpetual inventory method with geometric depreciation rate is used to construct capital series from observed levels of real investment,

$$K_{it+1} = (1 - \delta)K_{it} + I_{it},$$

where I_{it} represents real investment and δ represents the rate of depreciation. For example, the rate of depreciation is approximately 2 per cent for housing; 4 per cent for oil and gas pipelines; 5 per cent for trains; 10 per cent for helicopters, ships and airplanes; 20 per cent for cars, trucks, and buses; and 50 per cent for intangibles. Valuables do not depreciate. The choice of depreciation rates for capital objects in the Norwegian National Accounts corresponds to the levels chosen in Sweden, Germany, and Canada. Further details about the construction of capital levels can be found in Todsén (1997).

Table 5.1 shows how the wage premium, skill intensity, and cost share have developed between 1972 and 1986 and between 1987 and 2007. Between 1972 and 1986, the only sector that experienced an increase in the wage premium was Construction. In the time period 1987–2007, the Construction sector also experienced a decrease in the wage premium. In this latter time period, only the Financial intermediates sector experienced an increase in the wage premium.³⁶ The wage premium in this sector was the lowest of all sectors in 1987. A flexible labour market with mobility between sectors could cause the wage premium to converge across sectors. Note that the variation in wage premium decreased over the sample period in line with such convergence and that the wage of a high-skilled was roughly 1.4–1.5 that of an unskilled in most sectors in 2007.

The lowering of the wage premium has occurred in tandem with an increase in skill intensity. This general increase in skill intensity more than offsets the lowering of the

³⁵http://statbank.ssb.no/statistikkbanken/default_fr.asp?PLanguage=1

³⁶I refer to Hægeland and Kirkebøen (2007) and references therein for a detailed analysis of wage differentials across educational groups. Hægeland and Kirkebøen (2007) find an increasing wage premium during the nineties. The data used in Table 5.1 shows no such tendency. Note that Hægeland and Kirkebøen (2007) use a trimmed data set, i.e., only full-time workers (more than 30 hours per week) and exclude workers who were registered as unemployed or who left or started a new job during the year. They also exclude workers born outside Norway. Furthermore, they exclude workers with less than seven years of education as well as workers with particularly high or low income. In sum, they exclude up to 50 per cent of the data material within each category. In contrast, since the focus is on the macro economy, I do not exclude anything in my material. Also, since I aim for a measure of marginal cost (W), I use hourly wage costs while they analyse differences in full-time income. These differences should be taken into account when comparing Table 5.1 with the results from Hægeland and Kirkebøen (2007).

TABLE 5.2: Total factor productivity growth

	1975 – 1986	1987 – 1997	1998 – 2007
15 Consumption goods	1.95	1.73	1.92
25 Misc. manufacturing	1.00	0.45	2.66
30 Energy intensive manufacturing	3.57	2.61	0.99
45 Engineering products	1.95	1.76	3.10
50 Oil platforms and ships	2.07	0.73	1.47
55 Construction	1.89	2.18	-2.17
63 Financial intermediates	-2.19	-1.94	3.80
64 Oil and gas exploration	4.03	4.45	-0.76
71 Electricity	0.68	1.29	4.09
74 Domestic transportation	1.69	3.58	3.37
81 Wholesale and retail trade	4.25	4.70	6.72
85 Other private services	1.21	1.22	1.33

The table shows the mean growth rates in per cent, i.e., $\frac{100}{T} \sum_t \Delta \ln TFP_t$, where the TFP_t series have been smoothed with the Hodrick-Prescott filter using the smoothing parameter $\lambda = 100$.

wage premium and has led to an overall increase in the cost share of high-skilled in both time periods. There are, however, variations in the development of the cost share between the two time periods. In particular, there was a surge in the cost share of high-skilled in the Oil and gas exploration sector from 0.06 in 1972 to 0.39 in 1986. This surge should be viewed in connection with the initial development of the Norwegian oil boom that began with the discovery of the Ekofisk oilfield. Production from the field started in June 1971, and several large discoveries such as Statfjord (1974), Gullfaks (1978), Oseberg (1979), and Troll (1983) were made during the following years (Ministry of Petroleum and Energy and Norwegian Petroleum Directorate, 2013). Even though the increase in the cost share continued in the latter time period, the increase was modest and in line with development in other sectors, reaching a level of 0.43 in 2007. In the empirical section, I return to the particular development in the Oil and gas exploration sector.

Table 5.2 shows TFP growth across sectors in the time periods 1975-1986, 1987-1997, and 1998-2007. There was particularly high productivity growth between 1975 and 1986 in Energy intensive manufacturing and in Wholesale and retail trade, with an average growth of 3.57 and 4.03 per cent respectively. These two sectors experienced quite different productivity growth rates towards 2007. While productivity growth decreased to an average of 0.99 between 1998-2007 in Energy intensive manufacturing, the already high level of productivity growth between 1975-1986 in Wholesale and retail trade increased further, reaching an average of 6.72 between 1998 and 2007. From the 1990s, the Wholesale and retail trade industry has undertaken both horizontal and vertical integration. There has also been a surge in shopping malls since the late 1980s; see

Rasmussen and Reidarson (2007). These developments are consistent with the efficiency gains illustrated in Table 5.2. There has also been an increase in productivity growth in Other private services; Domestic transportation; Electricity; and Financial intermediates. Between 1998 and 2008, five sectors experienced average TFP growth higher than 3 per cent: Engineering products; Financial intermediates; Electricity; Domestic transportation; and Wholesale and retail trade.

5.5 Econometric results

The econometric results are presented in three parts. In the first part, I discuss the estimates of SBTC based on the VEqCM and the simplified models from Assumptions 1 to 6. In the second part, the identification of a sector bias of SBTC is discussed, and in the third part, the identification of a sector bias of TFP is analysed.

5.5.1 Identifying SBTC

In Table 5.3, estimates of the cost share function Equation 5.3 are reported together with the adjustment coefficients.³⁷ The lag structure was chosen so as to whiten the residuals, with particular focus on avoiding autocorrelation.³⁸

There is wide variation in how the wage premium impacts the high-skilled cost share (b_2). In Energy intensive manufacturing; Oil and gas exploration; and Other private services, an increase in the wage premium leads to a lowering of the cost share of high-skilled, indicating that these sectors are characterised by great substitutability between the high- and low-skilled labour, as shown in the last column. In contrast, the insignificant estimates in many of the other sectors could be interpreted by how price and quantity effects cancel out. When the wages of high-skilled increase, more unskilled workers are employed, but the change in employment is not large enough to significantly impact the cost share of high-skilled (*ceteris paribus*). An elasticity of substitution equal to unity is consistent with the Cobb-Douglas production function.

Capital is treated as a quasi-fixed factor of production. A significant positive estimate of capital intensity (b_3) implies that capital is complementary to skilled labour, that is, skilled workers are more efficient in utilising capital equipment than unskilled workers.

³⁷The results of the trace statistics used in testing for the cointegration rank can be found in the appendix; see Table D.1. I assume that the cointegration rank is common across sectors, and I impose one cointegration relation in all sectors.

³⁸Tests for autocorrelation are shown in the appendix; see Table D.2.

TABLE 5.3: VEqCM: estimates of the translog cost share function

	\hat{b}_2	\hat{b}_3	\hat{b}_1	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	Lags	σ
15 Consumption goods	-0.02 (0.04)	0.01 (0.01)	2.46** (0.21)	-0.42** (0.12)	0.08 (0.55)	2.51 (2.50)	1	1.3
25 Misc. manufacturing	0.08 (-)	0.07** (0.01)	4.41** (0.15)	-0.68** (0.16)	-0.49 (0.92)	1.00 (2.05)	4	0.5
30 Energy intensive manufact.	-2.58** (0.42)	1.21** (0.20)	7.04** (2.56)	-0.06** (0.03)	-0.26** (0.04)	0.37 (0.39)	4	16.1
45 Engineering products	-0.01 (0.11)	0.14** (0.02)	2.41** (0.51)	-0.32** (0.07)	-0.10 (0.23)	0.25 (0.99)	1	1.1
50 Oil platforms and ships	0.13 (-)	0.10** (0.01)	3.84** (0.23)	-0.36** (0.16)	-0.92** (0.20)	1.59 (2.53)	2	0.2
55 Construction	0.05 (-)	-0.44 (0.16)	8.90 (3.68)	-0.04 (0.02)	-0.07 (0.08)	-0.52 (0.29)	1	0.4
63 Financial intermediates	0.19 (-)	0.07** (0.03)	2.79 (1.72)	-0.12* (0.10)	0.34* (0.25)	-2.01** (0.66)	3	0.2
64 Oil and gas exploration	-0.56** (0.09)	0.10** (0.03)	3.41** (0.80)	-0.35** (0.04)	0.30** (0.06)	1.83** (0.57)	1	3.4
71 Electricity	0.17 (-)	-0.15** (0.02)	4.50** (0.28)	-0.59** (0.19)	-0.38* (0.46)	-3.20 (2.87)	4	0.2
74 Domestic transportation	0.05 (-)	-0.08 (0.04)	4.44 (0.66)	-0.13 (0.05)	0.05 (0.21)	-0.58 (0.97)	1	0.5
81 Wholesale and retail trade	-0.06 (0.05)	0.02 (0.01)	4.33 (0.76)	-0.27* (0.09)	-0.84 (0.57)	-3.14 (1.77)	1	1.5
85 Other private services	-2.42** (0.40)	-0.15 (0.11)	0.13 (1.80)	-0.10** (0.02)	-0.27** (0.06)	0.06 (0.17)	1	11.2

The estimate of b_1 is multiplied with 10^3 . k refers to the number of lags in the VEqCM model: $\Delta \mathbf{x}_{it} = \tilde{\gamma}_i + \Gamma_{1i} \Delta \mathbf{x}_{it-1} + \dots + \Gamma_{ki} \Delta \mathbf{x}_{it-k} + \Pi_i \tilde{\mathbf{x}}_{it-1} + \epsilon_{it}$. The LR statistic have been applied to test if the coefficients are significantly different from zero. Rejection at the 10 per cent significance level is indicated with * and ** indicates rejection at the 5 per cent significance level. Asymptotic standard errors are reported in brackets. The last row shows the elasticity of substitution $\sigma = 1 - b_2/(\hat{S}(1 - \hat{S}))$ where \hat{S} is the mean cost share of high-skilled. In some sectors \hat{b}_2 have been restricted by $\hat{b}_2 = \min_t S_t(1 - S_t)$ to ensure a positive elasticity of substitution, marked with (-).

Misc. manufacturing; Energy intensive manufacturing; Engineering products; Oil platforms and ships; Financial intermediates; and Oil and gas exploration are characterised by significant complementarity towards the skilled while there is significant complementarity towards the unskilled in the Electricity sector only.

There is evidence of SBTC, i.e., a significant positive estimate of b_1 , in most sectors. In Construction; Financial intermediates; Domestic transportation; Wholesale and retail trade; and Other private services, the estimates of SBTC are positive but not significantly different from zero. Technical change has been particularly skill-biased in Energy intensive manufacturing and Electricity.

Table 5.4 shows the estimates of SBTC (b_1) in the models where Assumptions 1–6 have been imposed. This table should be analysed in conjunction with Table 5.5 where the imposed assumptions are empirically tested. Assumption 1 is empirically rejected in

TABLE 5.4: Estimates of SBTC with different models

	VEqCM	A1	A2	A3	A4	A5	A6
15 Consumption goods	2.5** (0.2)	2.5** (0.8)	2.5** (0.8)	2.7** (0.6)	3.0	3.1	5.5
25 Misc. manufacturing	4.4** (0.2)	4.7** (1.8)	4.3 (1.8)	5.0** (0.6)	5.0	5.0	7.5
30 Energy intensive manufact.	7.0** (2.6)	2.1** (0.9)	2.6 (1.3)	3.9** (1.2)	4.1	4.1	6.0
45 Engineering products	2.4** (0.5)	2.4** (1.0)	2.4** (0.4)	2.8** (1.1)	2.6	2.5	3.4
50 Oil platforms and ships	3.8** (0.2)	7.7** (2.0)	7.6** (1.7)	4.9** (1.6)	3.5	3.4	4.4
55 Construction	8.9 (3.7)	3.1** (1.3)	3.9** (1.6)	1.8** (0.7)	1.5	1.6	3.9
63 Financial intermediates	2.8 (1.7)	5.6** (2.4)	17.3* (6.2)	7.4** (1.9)	8.2	8.3	9.4
64 Oil and gas exploration	3.4** (0.8)	2.5** (0.9)	-0.2 (0.0)	6.4* (3.4)	11.5	11.5	12.6
71 Electricity	4.5** (0.3)	6.4** (2.0)	8.6* (4.4)	6.4** (1.8)	5.9	5.9	6.3
74 Domestic transportation	4.4 (0.7)	4.6* (2.2)	1.2 (0.6)	5.0** (1.0)	4.9	4.8	5.3
81 Wholesale and retail trade	4.3 (0.8)	7.0** (3.1)	7.1** (2.4)	4.4** (0.9)	4.8	4.7	4.5
85 Other private services	0.1 (1.8)	2.0 (1.5)	0.3 (0.1)	3.5** (0.8)	3.3	3.4	5.3

Standard errors are reported in parentheses. The estimate of SBTC (b_1) is multiplied with 10^3 . The LR statistic have been applied to test if the coefficients are significantly different from zero in the VEqCM model. Rejection at the 10 per cent significance level is indicated with * and ** indicates rejection at the 5 per cent significance level. In models A1 and A2, the test of significance is made with respect to the short term parameter $\alpha_1 b_1$. Standard errors are computed by dividing the standard error of the short term parameter $\alpha_1 b_1$ with the estimate of the adjustment coefficient $\widehat{\alpha_1}$. Note that the method in Bårdsen (1989) can be applied to test if b_1 is significantly different from a value that is not equal to zero.

all sectors except for Consumption goods; Engineering products; and Wholesale and retail trade. Imposing this restriction changes the estimate significantly in, for example, Energy intensive manufacturing and Domestic transportation. Given that Assumption 1 is already imposed, further restricting the model by imposing Assumption 2 is rejected in almost every sector.³⁹ Given that both Assumptions 1 and 2 have been imposed,

³⁹Given that the residuals from the VEqCM model are multivariate normal, the test for weak exogeneity of the wage premium and capital intensity (Assumption 1) is valid. However, the sequential testing procedure in Table 5.5 is not generally appropriate, and the test statistics should be interpreted with a grain of salt. For example, if test of Assumption 2 is rejected, as is the case in Misc. manufacturing, the consecutive test of Assumptions 3 is made with reference to a model with no empirical support. In order to reduce the magnitude of this problem, I have used robust standard errors that take both

TABLE 5.5: Testing assumptions 1 to 5

	Assumptions				
	1	2	3	4	5
15 Consumption goods	0.9	9.4**	-2.9**	1.8	-1.4
25 Misc. manufacturing	22.6**	3.7**	-2.8**	0.2	0.1
30 Energy intensive manufact.	31.2**	6.2**	-3.5**	0.5	-0.6
45 Engineering products	0.1	0.4	-9.9**	0.8	-1.7*
50 Oil platforms and ships	5.5*	2.3*	-5.2**	6.4**	-1.1
55 Construction	12.9**	1.0	-6.4**	31.0**	-2.5**
63 Financial intermediates	18.2**	15.7**	-3.9**	45.8**	2.5**
64 Oil and gas exploration	18.8**	4.4**	-5.8**	8.8**	5.2**
71 Electricity	8.4**	24.3**	-2.8**	0.8	0.8
74 Domestic transportation	5.5*	6.5**	-2.3**	1.4	0.0
81 Wholesale and retail trade	2.9	0.9	-4.7**	4.7**	-0.0
85 Other private services	14.5**	2.5*	-4.6**	1.6	-1.2
Model	VEqCM	A1	A2	A3	A4
Test	$\alpha_{2i} = 0$ $\alpha_{3i} = 0$	$\tilde{\Gamma}_{ji} = \mathbf{0}$ $\forall j$	$\alpha_{1i} = 0$	$b_{2i} = b_2$ $b_{3i} = b_3$	$b_{1i} = b_1$
Test statistic	χ^2	F -value	t -value	F -value	t -value

Robust standard errors that take both heteroskedasticity and autocorrelation into account (Newey and West) are used in models A1, A2 and A3. In the panel model, A4, robust standard errors that handle between-period correlation (cross-section clustering) have been imposed; see Beck and Katz (1995). Rejection at the 10 per cent significance level is indicated with * and ** indicates rejection at the 5 per cent significance level.

the hypothesis that Assumption 3 can also be imposed is rejected at the 5 per cent significance level in all sectors. Models A4, A5, and A6 are thus rejected in all sectors. The estimates of SBTC vary across models, particularly in Financial intermediates and Oil and gas exploration, where all assumptions were rejected at the 5 per cent level. Since both of these sectors experience a high level of skill intensity, this variation will impact the estimate of a sector bias.

5.5.2 Identifying a sector bias of SBTC

If the sector bias hypothesis is relevant, one should find a systematic relationship between the level of sector-specific technical change and skill intensity. The previous section discussed the sector-specific level of technical change and how it changed when imposing

heteroskedasticity and autocorrelation into account. In the panel model, A4, I have imposed robust standard errors that handle between-period correlation (cross-section clustering); see Beck and Katz (1995) and (Quantitative Micro Software, 2010, p. 611).

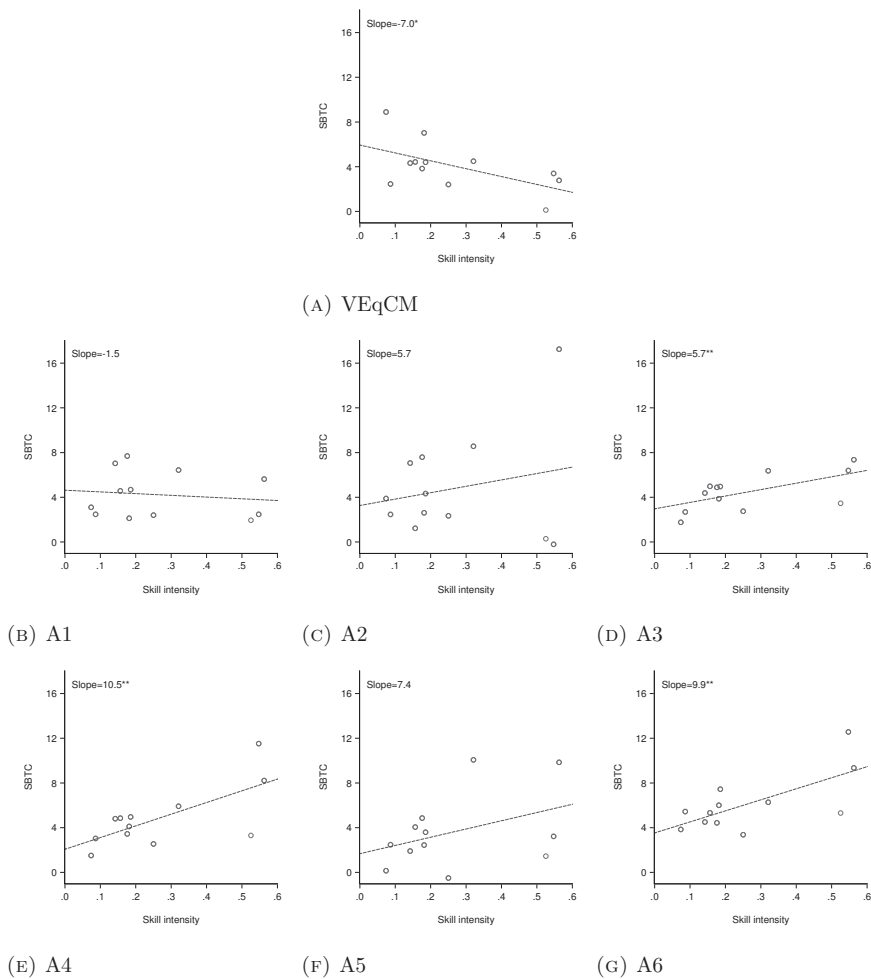


FIGURE 5.1: The sensitivity of key assumptions. The y axis measures SBTC while the x axis measures skill intensity at the 1990 level, i.e., the relative number of man-hours of skilled and unskilled (H/L). The OLS regression line specified in Equation 5.2 is included. Significance of the γ_2 slope coefficient is indicated by * at the 10 per cent significance level and by ** at the 5 per cent significance level.

Assumptions 1–6. The purpose of Figure 5.1 is to illustrate how the conclusion regarding a sector bias can change when imposing Assumptions 1–6. Note that, in contrast to Haskel and Slaughter (2002) and Esposito and Stehrer (2009), which focused on manufacturing sectors only, both manufacturing and services sectors are included. Also, following Haskel and Slaughter (2002), all sectors are included irrespective of the size of the elasticity of substitution. The estimate of the parameter γ_2 from Equation 5.2 is shown in all sub-figures.

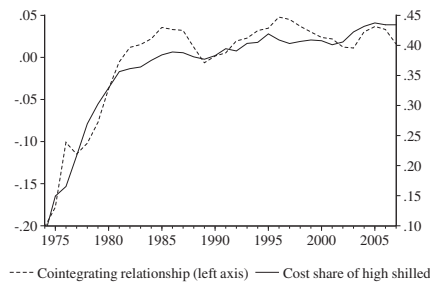


FIGURE 5.2: The Oil and gas exploration sector

In Figure 5.1a, which is based on the most general VEqCM specification, there is a significant negative relationship between skill intensity and SBTC. The estimate of γ_2 is still negative when imposing Assumption 1, but it becomes insignificant. However, when also imposing Assumption 2, the insignificant negative estimate changes to an insignificant positive estimate. This change can mostly be traced back to the increased estimate of SBTC in Financial intermediates. Imposing Assumption 3 does not change the positive estimate of γ_2 , but now the estimate is significantly different from zero at the 10 per cent significance level. Imposing further Assumptions 4, 5, and 6 yields a higher estimate of γ_2 . As a result, applying the framework used in the literature therefore leads to the conclusion that there has been a significant positive sector bias in Norway.

Trying to pinpoint exactly why the estimates of γ_2 change when more assumptions are imposed can lead the discussion astray. However, the results from the Oil and gas exploration sector shed light on two general problems with the framework used in the literature. Figure 5.2 shows the cointegration relationship ($\beta\tilde{x}_{t-1}$) in this sector together with the cost share of high-skilled (S_t). Initially, the cost share of high-skilled is far from equilibrium, as shown by the cointegration relationship. It takes about seven years until the cointegration cost share schedule is in equilibrium. The general VEqCM specification allows for such initial disequilibrium. The rapid increase in the cost share of high-skilled in the 1970s, which occurred when the Norwegian oil boom began, is in this framework interpreted as a process of equilibrium correction. SBTC was estimated to be 3.4×10^{-3} . In contrast, in a pure difference approach, such as models A3–A6, there is no equilibrium correction. The rapid increase in the cost share of high-skilled in the 1970s will therefore be interpreted as SBTC. This explains the estimated level of SBTC in model A3 of 6.4×10^{-3} , which is significantly higher than the VEqCM estimate. To check that the initial disequilibrium is the cause of the bias, I re-estimate model A3 beginning in a year where the cost share schedule was roughly in equilibrium. It can be seen from the cointegration relationship in Figure 5.2 that the cost share schedule

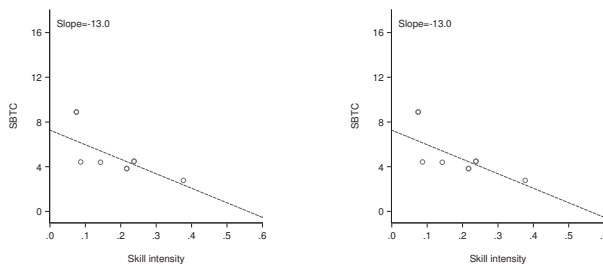
(A) Complements, $\sigma_i < 1$ (B) Substitutes, $\sigma_i > 1$

FIGURE 5.3: The sector bias of SBTC. The y axis measures SBTC while the x axis measures skill intensity (H/L) in 1990. The OLS regression line specified in Equation 5.2 is included. Significance of the slope coefficient is indicated by * at the 10 per cent significance level and by ** at the 5 per cent significance level.

is roughly in equilibrium in 1982. Re-estimating model A3 starting in 1982 lowers the estimate of SBTC to 4.0×10^{-3} , which is not significantly different from the VEqCM estimate. Therefore, as the results from the Oil and gas exploration sector have shown, using an econometric framework that does not take initial disequilibrium into account can lead to biased estimates.

The second problem with the cross-section model is the assumed homogeneous slope parameters. In the Oil and gas exploration sector, the estimated level of SBTC was $\hat{b}_1^{A3} = 6.4 \times 10^{-3}$ in model A3 while the estimated level in model A4 was $\hat{b}_1^{A4} = 11.5 \times 10^{-3}$. Decomposing the difference between these estimates according to Equation 5.5 yields

$$\begin{aligned} \hat{b}_1^{A3} - \hat{b}_1^{A4} &= (\hat{b}_2 - \hat{b}_{2,64}) \overline{\Delta \ln(W_H/W_L)_{64}} + (\hat{b}_3 - \hat{b}_{3,64}) \overline{\Delta \ln(K/Y)_{64}} \\ &= -5.2 \times 10^{-3} + 0.1 \times 10^{-3} = -5.1 \times 10^{-3}, \end{aligned}$$

where the values $\hat{b}_2 = .0569$, $\hat{b}_{2,64} = -.4289$, $\hat{b}_3 = .0001$, $\hat{b}_{3,64} = .0045$, $\overline{\Delta \ln(W_H/W_L)_{64}} = -.0108$ and $\overline{\Delta \ln(K/Y)_{64}} = -.0290$ have been used and where 64 is the industry code for the Oil and gas exploration sector. The estimate $\hat{b}_{2,64} = -.4289$ indicates that the Oil and gas exploration sector is characterised by great substitutability between high- and low-skilled labour. Since the “average” sector in contrast is characterised by low substitutability, $\hat{b}_2 = .0569$, the error of assuming the same type of labour substitutability across sectors is significant in the Oil and gas exploration sector. As the decomposition shows, it is the impact of wrongly imposing a homogeneous effect from the wage premium that causes the increased estimate of SBTC. Moreover, if one has erroneously imposed homogeneous slope parameters in the first stage, the second stage of the estimation procedure Equation 5.2 will wrongfully include all sectors, irrespective of the true size of the elasticity of substitution.

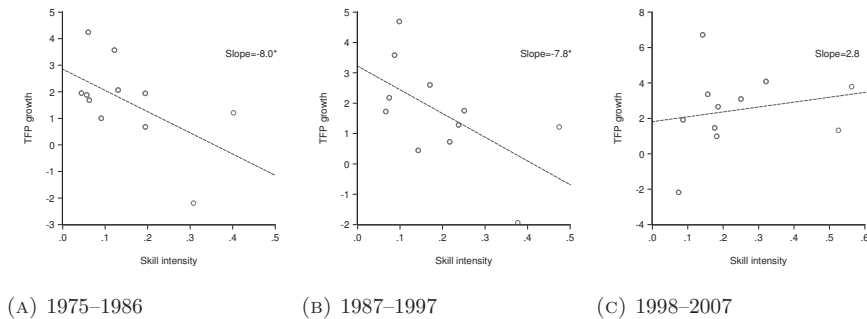


FIGURE 5.4: The Sector Bias of TFP. The y axis measures smoothed TFP growth while the x axis measures skill intensity (H/L) in (a) 1980, (b) 1990 and (c) 2000. The TFP series has been smoothed with the Hodrick-Prescott filter using the smoothing parameter $\lambda = 100$. The OLS regression line specified in Equation 5.8 is included. Significance of the slope coefficient ϕ_2 is indicated by * at the 10 per cent significance level and by ** at the 5 per cent significance level.

The impact of a sector bias of SBTC depends on whether a sector is characterised by elasticity of substitution in production higher or lower than unity. To identify the sector bias of SBTC, Figure 5.3 plots SBTC against the skill intensity separately for sectors where factors of production are complements Figure 5.3a and substitutes Figure 5.3b. In neither of the two cases is the slope coefficient significantly different from zero. However, the negative relationship between SBTC and skill intensity in Figure 5.3b shows that SBTC has mainly occurred in sectors with a low skill intensity. This is consistent with a rising wage premium when the elasticity of substitution of demand is low, or with a decreasing wage premium if the elasticity of substitution of demand is high. The lack of a significant estimate of γ_2 should be viewed in conjunction with the sample size. As there are only six sectors in each subfigure, the empirical evidence presented provides neither clear support for a sector bias of SBTC nor clear rejection of a sector bias of SBTC.

5.5.3 Identifying a sector bias of TFP

Figure 5.4 plots the average TFP growth over the time periods 1975–1986, 1987–1997 and 1998–2007 against skill intensity evaluated in 1980, 1990, and 2000 respectively. The Oil and gas exploration sector has been excluded from the sample since increased extraction of oil and gas, which represents economic rent, ends up as TFP in the index formula Equation 5.7. Further, to control for business cycles, the TFP indices have been chained and smoothed with the Hodrick-Prescott filter using a smoothing parameter $\lambda = 100$.

There is a clear shift in trend between the time periods. Between 1975 and 1997, TFP growth was highly concentrated in low-skilled sectors. This is consistent with the sector

bias hypothesis, i.e., a rising relative wage rate if the elasticity of substitution in demand is low and a falling relative wage rate if the elasticity of substitution in demand is high. In the time period 1998–2007, this relationship changes. TFP growth becomes higher in high-skilled sectors and lower in low-skilled sectors. The negative relationship between TFP growth and skill intensity observed between 1975 and 1997 has disappeared. The empirical evidence points to a sector bias of TFP from the 1970s to the 1990s, but the impact of the sector bias reduced towards the latter part of the sample period.

5.6 Conclusions

The sector bias of technical change is a theoretical result, implying that the skill intensity of the sector where technical change occurs matters for the development of the wage premium. Identifying the importance of a sector bias is therefore crucial in understanding the development of the wage premium. The empirical literature studying a sector bias of technical change has only focused on skill-biased technical change. In this chapter, I have analysed the sector bias of both factor-neutral and factor-biased technical change. In Norwegian data from 1972 to 2007, the empirical evidence is not clear on the impact of a sector bias of skill-biased technical change, but it points to a sector bias of factor-neutral technical change from the 1970s to the 1990s. That said, the impact of the sector bias seems to have gradually reduced towards the latter part of the sample period. I also evaluated the cross-section model used in the literature and showed that strong restrictions must be placed on a vector equilibrium correction model to end up with this model. If these restrictions do not hold, the results reported in the literature may be biased. I showed that the restrictions were strongly rejected, and erroneously imposing them significantly changed the estimates of skill-biased technical change in many sectors. The results from the Oil and gas exploration sector shed light on two general problems with the framework used in the literature. It was shown that what is interpreted as equilibrium correction in the VEqCM is wrongfully interpreted as SBTC in the cross-section model. Also, assuming high- and low-skilled labour to be either substitutes or complements leads to a large bias of SBTC. By using a VEqCM specification, the pitfalls of the cross-section model can be avoided.

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Appendix A

Appendix to Chapter 2

A.1 The Èltetö-Köves-Szulc (EKS) index

An index number formula PPP_{jk} is said to satisfy the transitivity property if and only if for all choices of j, k and l , the index satisfies $PPP_{jk} = PPP_{jl} \times PPP_{lk}$. (ILO et al., 2004b, p. 497). The transitivity property implies that attaining the PPP between Norway and Germany directly is equivalent to the indirect comparison between Norway and a third country, and the third country and Germany. The EKS method yields a transitive index. Although the transitivity property is an important requirement, as pointed out by Deaton and Heston (2010), the transitivity property implies that “the price index for any pair of countries depends on prices and budget shares in third countries, a violation of the independence of irrelevant country property” (p. 8). As shown by Veelen (2002), any method of comparing wealth of nations must violate either the independence of irrelevant country property, or one of three other reasonable requirements.⁴⁰ However, when countries have relatively similar structures, which is the case for the countries in this article, the EKS index is not very sensitive to budget shares in third countries. This follows since the EKS method also attempts to provide PPPs that retain the essential features of indices comparing pairs of countries separately, i.e., the index deviates least from pairwise Fisher binary comparisons (Eurostat and OECD, 2012, p. 245). The EKS index PPP^{EKS} for a particular industry aggregation, e.g., manufacturing, is calculated as a geometric mean of all the indirect Fisher indices PPP^F between countries j and k

$$PPP_{jk}^{EKS} = \prod_{l=1}^M (PPP_{jl}^F \times PPP_{lk}^F)^{1/M}. \quad (\text{A.1})$$

⁴⁰The three properties are Weak continuity, Dependence on prices and Weak Ranking Restrictions.

The Fisher index is the geometric average between the Paasche (PPP^P) and Laspeyres indices (PPP^L)

$$PPP_{jl}^F = (PPP_{jl}^L \times PPP_{jl}^P)^{1/2}. \quad (\text{A.2})$$

The Laspeyres and Paasche indices are defined by

$$PPP_{jl}^L = \sum_{i=1}^I \frac{PPP_{ij}}{PPP_{il}} s_{il} \quad \text{and} \quad PPP_{jl}^P = \left(\sum_{i=1}^I \left(\frac{PPP_{ij}}{PPP_{il}} \right)^{-1} s_{ij} \right)^{-1},$$

where i runs across sub industries within manufacturing and where the weight s_{il} is industry i 's gross output share in manufacturing in country l .

A.2 PPPs for capital input

To calculate PPPs for capital input I have used the PPPs for gross fixed capital formation provided by OECD and Eurostat (2008). The use of PPPs for gross fixed capital formation implies the assumption that the relative price between capital and investment is equal between all countries. Following Inklaar and Timmer (2008, p. 35), if P^K denote the user cost of capital and P^I is the price of real gross fixed investments, the PPP for capital between country j and the USA can be written as

$$PPP_j^K = PPP_j^I \frac{P_j^K / P_j^I}{P_{USA}^K / P_{USA}^I}. \quad (\text{A.3})$$

Since I do not hold the user cost of capital for all countries it is assumed that the ratio of relative capital to investment prices are equal between countries, i.e., $P_j^K / P_j^I = P_{USA}^K / P_{USA}^I$ for all j , and that the PPPs for investment are good proxies for the PPPs for capital.

A.3 Mapping from ISIC Rev. 2 to ISIC Rev. 3

Longer time series for R&D were created by extending ISIC Rev. 3 data backwards in time using the growth rates of ISIC Rev. 2 data. To this end, the approximate mapping scheme outlined in the documentation of the STAN database (OECD, 2005, Annex 1, p. 25) were applied. This mapping is also illustrated in Table A.1. To illustrate how precise the approximation is, the percentage deviation (in absolute terms) between the official ISIC Rev. 3 data and the transformed ISIC Rev. 2 data for R&D expenditure in 1990 in Norway is shown in column 3 and 6 of Table A.1.

TABLE A.1: Approximate mapping from ISIC Rev. 2 to ISIC Rev. 3 – R&D expenditure in Norway in 1990

Rev. 3	Rev. 2	Deviation (%)	Rev. 3	Rev. 2	Deviation (%)
c01t99	b01t99	0.0	c30	b3825	0.0
c15t37	b3	0.0	c31	b383x	0.0
c15t16	b31	0.0	c32	b2832	0.0
c17t19	b32	0.2	c33	b385	0.0
c20	b33		c34	b3843	0.0
c21t22	b34		c351	b3841	0.0
c23t25	b35	0.0	c353	b3845	0.1
c24x	b3512x	0.0	c352a9	b3842a	0.5
c2423	b3522	0.0	c35	b3841+b3845+b3842a	0.0
c23	b3534a	0.0	c36	b39	
c24	b3512x+b3522	0.0	c40t99	b4t9	0.0
c25	b3556a	0.0	c40t41	b4	0.0
c26	b36	0.0	c45	b5	0.0
c27	b37	0.0	c60t63	b71	
c28	b381	0.0	c64	b72	
c29	b382x	0.0	c74	b8284	0.0

The table shows the approximate mapping between the 2nd and 3rd revision of the International Standard Industrial Classification in the STAN OECD database, see the documentation of the STAN database (OECD, 2005, Annex 1., p. 25). Columns 3 and 6 show the absolute value of the mean deviation of R&D expenditure in 1990 in Norway in current prices

A.4 Mapping from ISIC Rev. 3 to ISIC Rev. 4

The ISIC Rev. 4 was officially released 11 August 2008. Data in ISIC Rev. 3 format have been mapped to the new ISIC Rev. 4 classification using the approximate 2-digit mapping provided in The OECD Compendium of Productivity Indicators 2013 (OECD, 2013, Annex D). This mapping is also provided in Table A.2. To illustrate how precise the approximation is, the percentage deviation (in absolute value) between the official ISIC Rev. 4 data and the transformed ISIC Rev. 3 data for value added in current prices (*VALU*) between 1990 and 2000 across industries in Denmark is shown next to the industry codes. For many industries there is a close correspondence between the ISIC Rev. 4 series and the transformed ISIC Rev. 3 series. However for industries such as Computer, electronic and optical products (d26), Furniture, other manufacturing and repair and installation of machinery and equipment (d31t33), Warehousing and support activities for transportation (d52) and Professional, scientific, technical, administrative and support service activities (d69t82) the mean discrepancy between the two series was more than 10 per cent.

For some industries the approximation follows a one-to-one mapping between the classification systems. Some ISIC Rev. 3 industries are however split between two ISIC Rev. 4 industries. This is shown with an asterisk (*) in Table A.2. For example, the Post and

telecommunications industry (c64) is split between the two ISIC Rev. 4 industries Postal and courier activities (d53) and Telecommunications (d61). To calculate the two ISIC Rev. 4 industries one must provide a weighting scheme between the two industries, i.e., $X_{d53} = w_{d53}X_{c64}$ and $X_{d61} = w_{d61}X_{c64}$, where the weights are given by $w_{d53} = \frac{Y_{d53}}{Y_{d53}+Y_{d61}}$ and $w_{d61} = \frac{Y_{d61}}{Y_{d53}+Y_{d61}}$ for a given weighting variable Y . For most variables, such as value added, gross output and intermediate input, the weights were taken from OECD STAN ISIC Rev. 4 using $Y = X$. The weights were extrapolated using constant shares if needed. For some variables, the weighting variables differed from the variable being transformed. For example, the mapping of the capital stock used gross fixed capital formation (GFCF) as weighting variable.

For some variables the information at the ISIC Rev. 3 classification level was not detailed enough and the ISIC Rev. 3 data has been disaggregated before the mapping procedure were applied. For example, the real fixed capital stock were only available from EU KLEMS for the Pulp, paper, printing and publishing industry (c21t22) for the USA. However, to map the capital level to the ISIC Rev. 4 industries Printing and reproduction of recorded media (d18) and Publishing activities (d58), the Pulp, paper, printing and publishing industry (c21t22) were split into Pulp, paper and paper products (c21) and Printing and publishing (c22) using capital compensation as weighting variable. For some countries, there is thus greater uncertainty surrounding those industries where a one-to-one mapping was not sufficient.

Data for France are based on the ISIC Rev. 3 version of the STAN database. The data have been mapped to ISIC Rev. 4 and extrapolated backwards using the growth rates from the STAN ISIC Rev. 4 database. This was done since net capital was not available in the ISIC Rev. 4 database.

The EKS index requires a weight for gross output for all countries. To map the PPPs from Timmer et al. (2006) to ISIC Rev. 4 some assumption were made when information for gross output was not available. In particular, gross output for Postal and courier activities (d53) in Sweden were not available, and the auxiliary weight for this industry was created using the gross output from the aggregate industry Transportation and storage (d49t53) and multiplying with the share of d53 from d49t53 in Norway, i.e., $X_{d53,SWE} = X_{d49t53,SWE} \left(\frac{X_{d53,NOR}}{X_{d49t53,NOR}} \right)$. Correspondingly, auxiliary weights for Printing and reproduction of recorded media (d18), Publishing activities (d58), Audiovisual and broadcasting activities (d59t60) in France, and Electricity, gas, steam and hot water supply (c41) and Recycling (c37) in the USA was created using weights from Germany. Thus, also for the mapping of PPPs is there greater uncertainty surrounding those industries where a one-to-one mapping was not sufficient. To map the industry Chemical, rubber, plastics, fuel products and other non-metallic mineral products (d19t23) for

Norway as a sum of c23 to c26, the gross output for c23 to c26 is needed. Since there are currently only two operating oil refineries in Norway, the gross output for Coke, refined petroleum products and nuclear fuel (c23) and Chemicals and chemical products (c24) are not published in the main series of the National Accounts. However, in 1997, which is the benchmark year in Timmer et al. (2006), there were three refineries operating and Statistics Norway published gross output for these sectors separately in the Input-Output tables, see https://www.ssb.no/a/english/kortnavn/nr_en/supply_use.html.

Only value and price variables were mapped. Price indices were aggregated using the Törnqvist price index. After the mapping of value and price series, volume series were then constructed from the product rule., i.e., the identity of a value ratio being equal to a price ratio times a quantity ratio, see Frisch (1930).

TABLE A.2: Approximate mapping from ISIC Rev. 3 to ISIC Rev. 4, Value added in Denmark, 1990-2000

Rev. 4	Rev. 3	Deviation (%)	Rev. 4	Rev. 3	Deviation (%)
d01t99	c01t99	0.0	d35t39	c37+c40t41+c90	0.0
d01t03	c01t05	3.2	d36t39	c37+c41+c90	0.0
d01t02	c01t02	3.5	d37t39	c37+c90	0.0
d01	c01	4.0	d35	c40	0.0
d02	c02	7.7	d36	c41	0.0
d03	c05	0.0	d41t43	c45	0.0
d05t09	c10t14	0.7	d45t47	c50t52	0.5
d05t06	c10t12	0.7	d45t56	c50t55+c60t63	3.2
d07t09	c13t14	0.7	d45	c50	7.5
d10t33	c15t37	4.8	d46	c51	0.0
d10t12	c15t16	0.7	d47	c52	1.1
d10t11	c15	0.7	d49t53	c60t63	12.8
d12	c16	0.0	d49	c60	0.0
d13t15	c17t19	0.5	d50	c61	0.8
d13t14	c17t18	0.9	d51	c62	0.0
d15	c19	3.0	d52	c63	13.0
d16	c20	0.4	d53	c64*	0.0
d16t18	c20+c21+c22*	3.1	d55t56	c55	0.0
d17	c21	5.1	d58t63	c22*+c64*+c92*+c72	
d18	c22*	4.3	d59t60	c92*	0.8
d19	c23	0.0	d61	c64*	0.0
d19t23	c23t25+c26	0.6	d62t63	c72	7.5
d20t21	c24	0.6	d64t66	c65t67	0.2
d22t23	c25+c26	0.7	d64	c65	0.3
d22	c25	0.7	d65	c66	0.0
d23	c26	2.2	d66	c67	0.0
d24t25	c27t28	3.6	d68t82	c70t74	4.6
d24	c27	5.7	d68	c70	0.3
d25	c28	6.1	d69t82	c71t74	11.8
d26t28	c29t33	8.7	d72	c73	0.0
d26t27	c30t33		d84t99	c75t99	4.0
d26	c30+c32+c33	14.6	d84t88	c75+c80+c85	0.4
d27	c31	1.3	d84	c75	0.5
d28	c29	7.6	d85	c80	0.0
d29t30	c34t35	9.3	d86t88	c85	0.6
d29	c34	5.6	d90t99	c91+c92*+c93+c95	8.8
d30	c35	19.2	d90t93	c92*	0.8
d31t33	c36	44.9	d97t98	c95	0.0

The table shows the approximate mapping between the 3rd and 4th revision of the International Standard Industrial Classification in the STAN OECD database, see The OECD Compendium of Productivity Indicators 2013 (OECD, 2013, Annex D). Columns 3 and 6 show the absolute value of the mean deviation of value added in current prices (VALU) in Denmark between 1990 and 2000. The asterisk (*) indicates that the ISIC Rev. 3 industry is split between two ISIC Rev. 4 industries, e.g., $X_{d53} = w_{d53}X_{c64}$ and $X_{d61} = w_{d61}X_{c64}$, where the weights are given by $w_{d53} = \frac{Y_{d53}}{Y_{d53}+Y_{d61}}$ and $w_{d61} = \frac{Y_{d61}}{Y_{d53}+Y_{d61}}$ for a given weighting variable Y .

Appendix B

Appendix to Chapter 3

B.1 Approximation of unit value biases

The entering and exiting bias can be written as the ratio of the last two terms in Equation 3.2 and Equation 3.4

$$\left(\frac{1 + \sum_{i \in I_t^c} V_{it} / \sum_{i \in I} V_{it}}{1 + \sum_{i \in I_t^c} H_{it} / \sum_{i \in I} H_{it}} \right) \left(\frac{1 + \sum_{i \in I_{t-1}^c} V_{it-1} / \sum_{i \in I} V_{it-1}}{1 + \sum_{i \in I_{t-1}^c} H_{it-1} / \sum_{i \in I} H_{it-1}} \right)^{-1}. \quad (\text{B.1})$$

Given that the number of workers entering and exiting is small relative to the number of workers available in both time periods, and by applying the approximation $\ln(1+z) \approx z$ when z is small, the logarithm of the entering bias (the parenthesis in the middle) can be written as

$$\ln \left(\frac{1 + \sum_{i \in I_t^c} V_{it} / \sum_{i \in I} V_{it}}{1 + \sum_{i \in I_t^c} H_{it} / \sum_{i \in I} H_{it}} \right) \approx \sum_{i \in I_t^c} V_{it} / \sum_{i \in I} V_{it} - \sum_{i \in I_t^c} H_{it} / \sum_{i \in I} H_{it} \quad (\text{B.2})$$

$$= \frac{\sum_{i \in I_t^c} H_{it}}{\sum_{i \in I} H_{it}} \left(\frac{\sum_{i \in I_t^c} V_{it} / \sum_{i \in I_t^c} H_{it}}{\sum_{i \in I} V_{it} / \sum_{i \in I} H_{it}} - 1 \right) \quad (\text{B.3})$$

$$\approx \left(\frac{\sum_{i \in I_t^c} H_{it}}{\sum_{i \in I} H_{it}} \right) \ln \left(\frac{u_t(I_t^c)}{u_t(I)} \right), \quad (\text{B.4})$$

where the last equality follows from the approximation $z - 1 \approx \ln(z)$ when $z \approx 1$ and the definition of unit values as the aggregate labour costs relative to the number of hours worked, i.e., $u_t(Z) = \sum_{i \in Z} V_{it} / \sum_{i \in Z} H_{it}$ in any given set Z . Taking the exponential on the right hand side of Equation B.4, and by applying the corresponding approximation for the set of exiting workers, yields the approximate expression for the

aggregate entering and exiting unit value bias in Equation B.1

$$\left(\frac{u_t(I_t^c)}{u_t(I)} \right)^{\left(\frac{\sum_{i \in I_t^c} H_{it}}{\sum_{i \in I} H_{it}} \right)} \left(\frac{u_{t-1}(I_{t-1}^c)}{u_{t-1}(I)} \right)^{-\left(\frac{\sum_{i \in I_{t-1}^c} H_{it-1}}{\sum_{i \in I} H_{it-1}} \right)}. \quad (\text{B.5})$$

The two terms are the biases of entering and exiting workers, as given in Equation 3.13 and Equation 3.14, respectively.

B.2 Two-step biases

In this section we derive the TWO-STEP ENTERING BIAS in Equation 3.16 and the TWO-STEP EXITING BIAS in Equation 3.17. Since the workforce can be split into two complement sets consisting of those that are skilled (S) and those that are unskilled (U) so that $I_t = S_t \cup U_t$, the contribution from workers entering the workforce in Equation 3.4 can be approximately decomposed by⁴¹

$$\begin{aligned} \ln \left(1 + \sum_{i \in I_t^c} H_{it} / \sum_{i \in I} H_{it} \right) &= \ln \left(1 + \frac{\sum_{i \in S_t^c} H_{it} + \sum_{i \in U_t^c} H_{it}}{\sum_{i \in S} H_{it} + \sum_{i \in U} H_{it}} \right) \\ &\approx \psi_t(S, I) \left(\frac{\sum_{i \in S_t^c} H_{it}}{\sum_{i \in S} H_{it}} \right) + (1 - \psi_t(S, I)) \left(\frac{\sum_{i \in U_t^c} H_{it}}{\sum_{i \in U} H_{it}} \right) \end{aligned} \quad (\text{B.6})$$

where the weight $\psi_t(S, I)$ is the share of man-hours carried out by skilled among continuing workers evaluated at time t , i.e. $\psi_t(S, I) = \left(\frac{\sum_{i \in S} H_{it}}{\sum_{i \in I} H_{it}} \right)$. Correspondingly, the contribution from workers exiting the workforce in Equation 3.4 can then be approximately decomposed⁴²

$$\begin{aligned} \ln \left(1 + \sum_{i \in I_{t-1}^c} H_{it-1} / \sum_{i \in I} H_{it-1} \right)^{-1} \\ \approx -\psi_{t-1}(S, I) \left(\frac{\sum_{i \in S_{t-1}^c} H_{it-1}}{\sum_{i \in S} H_{it-1}} \right) - (1 - \psi_{t-1}(S, I)) \left(\frac{\sum_{i \in U_{t-1}^c} H_{it-1}}{\sum_{i \in U} H_{it-1}} \right). \end{aligned} \quad (\text{B.7})$$

These entering and exiting terms will be compared with the entering and exiting terms in the two-step procedure. The Törnqvist index across skilled and unskilled labour in

⁴¹Since $\ln(1+z) \approx z$ for $z \approx 0$.

⁴²Since $\ln(1+z)^{-1} \approx -z$ for $z \approx 0$.

Equation 3.15 can be written in logs as

$$\overline{v_t(S_t, I_t)} \ln \left(\frac{\sum_{i \in I_t} HS_{it}}{\sum_{i \in I_{t-1}} HS_{it-1}} \right) + \left(1 - \overline{v_t(S_t, I_t)} \right) \ln \left(\frac{\sum_{i \in I_t} HU_{it}}{\sum_{i \in I_{t-1}} HU_{it-1}} \right).$$

By applying Equation 3.4 for both skilled and unskilled, the Törnqvist index can *approximately* be decomposed into contributions from continuing, entering and exiting workers

$$\begin{aligned} \overline{v_t(S_t, I_t)} \ln \left(\frac{\sum_{i \in S} H_{it}}{\sum_{i \in S} H_{it-1}} \right) &+ \left(1 - \overline{v_t(S_t, I_t)} \right) \ln \left(\frac{\sum_{i \in U} H_{it}}{\sum_{i \in U} H_{it-1}} \right) \\ &+ \overline{v_t(S_t, I_t)} \left(\frac{\sum_{i \in S_t^c} H_{it}}{\sum_{i \in S} H_{it}} \right) + \left(1 - \overline{v_t(S_t, I_t)} \right) \left(\frac{\sum_{i \in U_t^c} H_{it}}{\sum_{i \in U} H_{it}} \right) \\ &- \overline{v_t(S_t, I_t)} \left(\frac{\sum_{i \in S_{t-1}^c} H_{it-1}}{\sum_{i \in S} H_{it-1}} \right) - \left(1 - \overline{v_t(S_t, I_t)} \right) \left(\frac{\sum_{i \in U_{t-1}^c} H_{it-1}}{\sum_{i \in U} H_{it-1}} \right). \quad (\text{B.8}) \end{aligned}$$

It follows that the (log of the) entering bias from using the two-step procedure can be approximated by the difference between the entering and exiting terms in the expression above with Equation B.6 and Equation B.7, respectively

$$\begin{aligned} \overline{v_t(S_t, I_t)} \left(\frac{\sum_{i \in S_t^c} H_{it}}{\sum_{i \in S} H_{it}} \right) &+ \left(1 - \overline{v_t(S_t, I_t)} \right) \left(\frac{\sum_{i \in U_t^c} H_{it}}{\sum_{i \in U} H_{it}} \right) \\ &- \left(\overline{\psi_t(S, I)} \left(\frac{\sum_{i \in S_t^c} H_{it}}{\sum_{i \in S} H_{it}} \right) + (1 - \overline{\psi_t(S, I)}) \left(\frac{\sum_{i \in U_t^c} H_{it}}{\sum_{i \in U} H_{it}} \right) \right). \end{aligned}$$

Taking the exponential of this expression yields the TWO-STEP ENTERING BIAS in Equation 3.16. Correspondingly, taking the exponential of the difference between the exiting terms in Equation B.8 and Equation 3.16 yields the TWO-STEP EXITING BIAS in Equation 3.17.

B.3 Contractual hours as a proxy for actual hours worked

In our analysis of measuring labour services contractual hours represents a proxy for actual hours worked. The purpose of this section is to evaluate the discrepancy between contractual hours and actual hours worked and to analyse if this discrepancy increased after 2005 when productivity growth slowed.⁴³ To this end, we will compare data on actual and contractual hours from register based statistics, the National Accounts and

⁴³See ILO (2008) for the different concepts of hours worked.

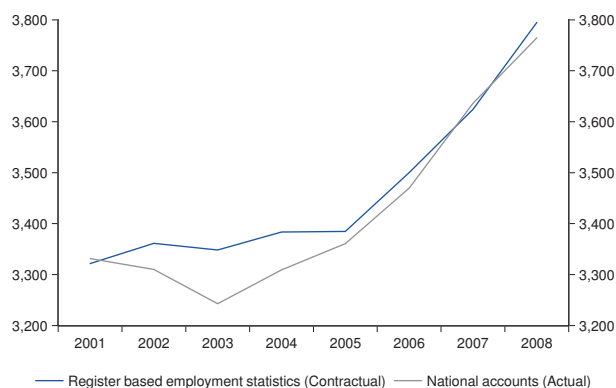


FIGURE B.1: Hours worked (Millions). Compares register based employment statistics for contractual hours worked with national accounts data on actual hours worked.

the Labour Force Survey (LFS). We will also take a closer look at aggregate rates for overtime and sickness absence.

Figure B.1 compares register-based employment statistics for contractual hours worked with national accounts data on actual hours worked. Both series start at about 3 300 million hours worked in 2001 and end at about 3 800 million hours worked. However, in the first couple of years, there is some discrepancy between the two series. While there is a modest increase in contractual hours worked from 2001 to 2005, the number of actual hours worked as measured by the National Accounts drops from 3 331 million hours worked in 2001 to 3 242 in 2003, before increasing to 3 360 in 2005. Although there are some discrepancies between these series in the short term, over the entire sample they show broadly the same increase in hours worked.

Figure B.2 shows actual and contractual working hours. The data represents the mean across 3rd quarter observations from the LFS. Workers with either actual or contractual weekly hours below 5 or higher than 90 are excluded. There has been a reduction in both weekly contractual and actual working hours from 2000 to 2009, from 35.6 to 35.2 and from 36.7 to 35.6, respectively. Although there was some variation between 2005 and 2008, neither contractual nor actual working hours changed much between these years: the mean contractual working hour was 35.3 in both 2005 and 2008 and the mean actual working hour was 36.0 in both 2005 and 2008. According to these data, the discrepancy between the two different measures of labour services in Table 3.3 between 2005 and 2008 can thus not be explained by differences between contractual and actual working hours.

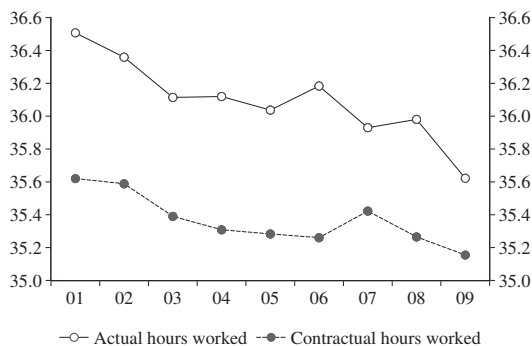


FIGURE B.2: Weekly actual and contractual hours worked. Mean across 3rd quarter observations from the Labour Force Survey. Workers with either actual or contractual weekly hours below 5 or higher than 90 hours are excluded. Source: Statistics Norway.

A different way to analyse the wedge between contractual and actual working hours is to look at overtime and sickness absence rates. The overtime rate is defined as the ratio of overtime hours to contractual hours and the sickness absence rate is defined as the ratio of sickness absence hours to contractual hours. In contrast to actual hours worked, contractual hours worked excludes irregular overtime and includes absence from work such as sickness absence. To illustrate, we let actual hours worked be defined as the sum of contractual hours worked and irregular overtime hours but excluding sickness absence, as a crude approximation. Moreover, let the overtime rate be defined by the ratio of overtime hours to contractual hours and let the sickness absence rate be defined by the ratio of sickness absence hours to contractual hours. It then follows that⁴⁴

$$\begin{aligned} \text{Percentage change in hours worked} &- \text{Percentage change in contractual hours} \\ &\approx \text{Change in overtime rate} - \text{Change in sickness absence rate.} \end{aligned}$$

The wedge between the percentage change in hours worked and contractual hours is thus the difference between the change in overtime and sickness absence rate, measured in percentage points.

Figure B.3 shows overtime and sickness absence rates measured in per cent. The overtime rate has been fairly constant ranging from 1.5 per cent in 2003 to 2.0 per cent in 2007 and 2008. In 2005 the overtime rate was 1.7 per cent. The change in overtime rate from

⁴⁴Let H_t denote actual hours worked at time t , C_t contractual hours worked, O_t irregular overtime hours and S_t sickness absence hours, where $H_t = C_t + O_t - S_t$, and let the overtime rate (r_t^O) be defined by $r_t^O = O_t/C_t$ and the sickness absence rate (r_t^S) by $r_t^S = S_t/C_t$. It follows that $H_t = C_t(1 + r_t^O - r_t^S)$. When the overtime and sickness absence rates are close to zero $H_t = C_t(1 + r_t^O - r_t^S)$ can be approximated as $\ln H_t - \ln C_t \approx r_t^O - r_t^S$, since $\ln(1 + z) \approx z$ for $z \approx 0$, and the first difference is given by $\Delta \ln H_t - \Delta \ln C_t \approx \Delta r_t^O - \Delta r_t^S$, which is the expression on this page.

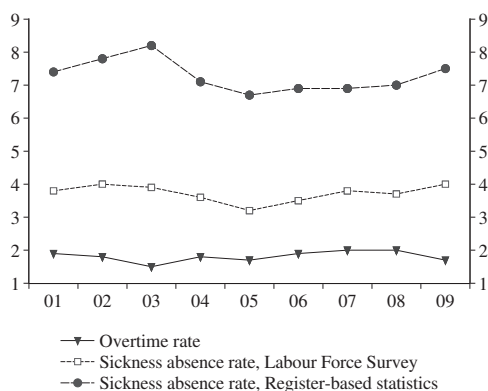


FIGURE B.3: Overtime and sickness absence rates. Per cent. Overtime rate is measured as the ratio of overtime hours to contractual hours. The target figure for sickness absence rate used in the Labour force survey is the number of employees who have been absent during the whole registration week in per cent of employees in total while register based statistics measure man-days lost due to own sickness as a percentage of contractual man-days. Source: Statistics Norway.

2005 to 2008 was thus 0.3 percentage points during these four years. Two measures of sickness absence rates are shown in Figure B.3. The measure used in the LFS is the number of employees who have been absent during the whole registration week in per cent of employees in total while register-based statistics measure man-days lost due to own sickness as a percentage of contractual man-days. Differences in levels between these series are due to how register-based statistics include persons on partial sick leave and also cases of sickness absence shorter than one week, which are not included in the absence rates from the LFS. In addition, the register-based statistics also take into account both the working time and the duration of the sickness absence when the portion of sickness absence is calculated. Although the levels between the two series differ, the changes in the series show broadly the same development. From 2005 to 2008 the sickness absence rate increased 0.6 percentage points from 3.2 to 3.8 per cent according to the LFS. According to register based statistics the increase was 0.3 percentage points from 6.7 to 7.0 per cent. Since increases in overtime and sickness absence rates have been small and since they have offsetting effects on the wedge between contractual and actual hours worked, the total impact from these changes is negligible.

The purpose of this section has been to evaluate contractual hours as a proxy for actual hours worked. Overall, both series show the same development from 2001 to 2008. Also, since the change in overtime rates and absence sickness rates have been very small, we conclude that it is not the wedge between these measures that explains the measured drop in productivity after 2005.

Appendix C

Appendix to Chapter 4

C.1 The bias in import prices due to trade barriers when goods are perfect substitutes

When goods are perfect substitutes, ($\rho = 1$), the index in Equation 4.10 can be written

$$\begin{aligned} I_t^{PS} &= \left(\sum_{j=1}^{n-1} p_{jt} x_{jt} + p_{nt} x_{nt-1} - p_{nt} \sum_{j=1}^{n-1} (\delta_j / \delta_n) (x_{jt} - x_{jt-1}) \right) / y_{t-1} \\ &= \left(\sum_{j=1}^{n-1} p_{jt} x_{jt} + p_{nt} x_{nt-1} - p_{nt} \sum_{j=1}^{n-1} (\delta_j / \delta_n) \Delta x_{jt} + \sum_{j=1}^{n-1} p_{jt} x_{jt-1} - \sum_{j=1}^{n-1} p_{jt} x_{jt-1} \right) / y_{t-1} \\ &= \left(\sum_{j=1}^{n-1} p_{jt} \Delta x_{jt} - p_{nt} \sum_{j=1}^{n-1} (\delta_j / \delta_n) \Delta x_{jt} + \sum_{j=1}^n p_{jt} x_{jt-1} \right) / y_{t-1} \\ &= \left(\sum_{j=1}^n p_{jt} x_{jt-1} \right) / y_{t-1} + \left(\sum_{j=1}^{n-1} (p_{jt} - (\delta_j / \delta_n) p_{nt}) \Delta x_{jt} \right) / y_{t-1} \\ &= I_t^L + \sum_{j=1}^{n-1} B_{jt}^{PS}. \end{aligned}$$

C.2 Proof: Proposition 4.1

The import price index when goods are perfect substitutes, defined in Equation 4.12, represents an upper bound to the true index (I_t^{CES}) if $I_t^{PS} - I_t^{CES} > 0$. It follows from

Equation 4.10 that

$$I_t^{PS} - I_t^{CES} = \frac{p_{2t}}{y_{t-1}} \left[(\delta_1/\delta_2)x_{1t-1} + x_{2t-1} - (\delta_1/\delta_2)x_{1t} - \left((\delta_1/\delta_2)x_{1t-1}^\rho + x_{2t-1}^\rho - (\delta_1/\delta_2)x_{1t}^\rho \right)^{1/\rho} \right].$$

This expression is positive only if

$$(\delta_1/\delta_2)x_{1t-1} + x_{2t-1} - (\delta_1/\delta_2)x_{1t} > \left((\delta_1/\delta_2)x_{1t-1}^\rho + x_{2t-1}^\rho - (\delta_1/\delta_2)x_{1t}^\rho \right)^{1/\rho}. \quad (C.1)$$

Without loss of generality, I define the following relationships: $c_1 \equiv x_{1t-1}/x_{2t-1}$ and $d_1 \equiv x_{1t}/x_{2t-1}$. Inserting these relationships into Equation C.1, and taking the natural logarithm, yields

$$\ln [1 + (\delta_1/\delta_2)(c_1 - d_1)] > (1/\rho) \ln [1 + (\delta_1/\delta_2)(c_1^\rho - d_1^\rho)].$$

When the increase in availability of x_{1t} is small, i.e., $\epsilon_1 = d_1/c_1$ is close to unity, it follows, from a first-order Taylor approximation, that⁴⁵

$$(c_1 - d_1) > (1/\rho)(c_1^\rho - d_1^\rho). \quad (C.2)$$

Inserting $c_1 = x_{1t-1}/x_{2t-1}$ and $d_1 = x_{1t}/x_{2t-1}$ yields

$$\left(\frac{x_{1t-1}}{x_{2t-1}} - \frac{x_{1t}}{x_{2t-1}} \right) > (1/\rho) \left(\frac{x_{1t-1}^\rho}{x_{2t-1}^\rho} - \frac{x_{1t}^\rho}{x_{2t-1}^\rho} \right).$$

Inserting $x_{1t} = \epsilon_1 x_{1t-1}$, and rearranging, yields

$$1 < \frac{x_{1t-1}^{\rho-1}}{x_{2t-1}^{\rho-1}} \frac{1 - \epsilon_1^\rho}{(1 - \epsilon_1)} (1/\rho),$$

where $\frac{x_{1t-1}^{\rho-1}}{x_{2t-1}^{\rho-1}}$ is the relative marginal rates of transformation: $TRS_{1t-1}^{CES}/TRS_{1t-1}^{PS}$ and $\frac{1 - \epsilon_1^\rho}{(1 - \epsilon_1)}(1/\rho)$ goes towards unity when ϵ_1 goes towards unity by L'Hôpital's rule. The opposite relationship, $TRS_{1t-1}^{CES} < TRS_{1t-1}^{PS}$, implies that $I_t^{PS} - I_t^{CES} < 0$, by the same arguments.

⁴⁵ $\ln(1 + z) \approx z$ around $z \approx 0$.

C.3 Proof: Proposition 4.2

Define the auxiliary variables $\epsilon_i \equiv x_{it}/x_{it-1}$, $c_i \equiv x_{it-1}/x_{nt-1}$ and $d_i \equiv x_{it}/x_{nt-1}$. The sets \mathcal{J} , \mathcal{A} and \mathcal{A}^c are given by $\mathcal{J} = \{1, 2, \dots, n-1\}$, $\mathcal{A}_t = \{j \in \mathcal{J} : 0 \leq x_{jt-1} \leq x_{nt-1}\}$ and $\mathcal{A}_t^c = \{j \in \mathcal{J} : x_{nt-1} < x_{jt-1} < x_{jt-1}^*\}$. The bias in Equation 4.11 can then be written

$$B_t^{CES} = \frac{x_{nt-1}}{y_{t-1}} \left(\sum_{i \in \mathcal{J}} p_{it}(d_i - c_i) - p_{nt} + p_{nt} \left(1 - \sum_{i \in \mathcal{J}} (\delta_i/\delta_n)(d_i^\rho - c_i^\rho) \right)^{1/\rho} \right)$$

The sum of individual biases when goods are perfect substitutes, for goods $i \in \mathcal{A}$, is given by

$$\sum_{i \in \mathcal{A}_t} B_{it}^{PS} = \frac{x_{nt-1}}{y_{t-1}} \left(\sum_{i \in \mathcal{A}_t} (d_i - c_i) (p_{it} - (\delta_i/\delta_n)p_{nt}) \right)$$

The index I_t^{PS} is said to represent an upper bound to the true index I_t^{CES} if $I_t^{PS} - I_t^{CES} > 0$. Since

$$I_t^{PS} - I_t^{CES} = \sum_{i \in \mathcal{A}} B_{it}^{PS} - B_t^{CES} = \frac{x_{nt-1}}{y_{t-1}} \left[- \sum_{i \in \mathcal{A}_t} (d_i - c_i)(\delta_i/\delta_n)p_{nt} - \sum_{i \in \mathcal{A}_t^c} (d_i - c_i)p_{it} + p_{nt} - p_{nt} \left(1 - \sum_{i \in \mathcal{J}} (\delta_i/\delta_n)(d_i^\rho - c_i^\rho) \right)^{1/\rho} \right],$$

the index I_t^{PS} is an upper bound if:

$$1 - \sum_{i \in \mathcal{A}_t} (d_i - c_i)(\delta_i/\delta_n) - \sum_{i \in \mathcal{A}_t^c} (d_i - c_i) \frac{p_{it}}{p_{nt}} > \left(1 - \sum_{i \in \mathcal{J}} (\delta_i/\delta_n)(d_i^\rho - c_i^\rho) \right)^{1/\rho}.$$

When the changes in trade barriers are small, i.e., d_i/c_i is close to unity for all i , it follows, from a first-order Taylor approximation, that⁴⁶

$$\sum_{i \in \mathcal{A}_t} (c_i - d_i)(\delta_i/\delta_n) + \sum_{i \in \mathcal{A}_t^c} (c_i - d_i) \frac{p_{it}}{p_{nt}} > (1/\rho) \sum_{i \in \mathcal{J}} (\delta_i/\delta_n)(c_i^\rho - d_i^\rho).$$

This is positive if the following conditions both hold

- i) $(c_i - d_i) > (1/\rho)(c_i^\rho - d_i^\rho)$ for $i \in \mathcal{A}_t$,
- ii) $(c_i - d_i) \frac{p_{it}}{p_{nt}} > (1/\rho)(c_i^\rho - d_i^\rho)$ for $i \in \mathcal{A}_t^c$.

⁴⁶ $\ln(1+z) \approx z$ around $z \approx 0$.

i) follows from Proposition 4.1 and Equation C.2. Since $c_i^\rho - d_i^\rho = \frac{x_{it-1}^\rho}{x_{nt-1}^\rho}(1 - \epsilon_i^\rho)$, it follows that *ii*) can be written as

$$TRS_{it-1}^{CES} > p_{it}/p_{nt} \text{ for } i \in \mathcal{A}_t^c,$$

since $\frac{1-\epsilon_i^\rho}{(1-\epsilon_i)}(1/\rho)$ goes towards unity when ϵ_i goes towards unity.

Appendix D

Appendix to Chapter 5

D.1 Translog cost function

Below I derive the econometric specification of the cost share and show the restrictions that follow from assuming constant returns to scale and price homogeneity. The translog cost function is given by

$$\ln C_{it} = \tilde{b}_{0,i} + \tilde{\mathbf{b}}_i' \ln(\mathbf{y}_{it}) + .5 \ln(\mathbf{y}_{it})' \tilde{\mathbf{B}}_i \ln(\mathbf{y}_{it}),$$

where the subscripts i and t denote sector and time respectively and $'$ is the transpose operator. The vector of right-hand-side variables (\mathbf{y}) include, for example the wage rate of skilled (W_H) and unskilled (W_L) labour, the level of production (Y), the volume of capital (K), and a deterministic time trend entering as an exponential function

$$\mathbf{y}_{it} = [W_H \quad W_L \quad Y \quad K \quad e^t]'_{it}.$$

Before any restrictions are imposed on the cost function, it holds in total 21 parameters including the intercept. There are five parameters in the vector \mathbf{b} where a typical element is denoted $\{b_k\}$, while there are 15 parameters in the symmetric matrix of the quadratic form $\tilde{\mathbf{B}}$ where a typical element is denoted $\{\tilde{b}_{jk}\}$ for $j, k = 1, \dots, 5$. Expanding the

expression for the translog Cost function yields

$$\begin{aligned}
\ln C_{it} &= \tilde{b}_{0,i} + \tilde{\mathbf{b}}_i' \ln(\mathbf{y}_{it}) + .5 \ln(\mathbf{y}_{it})' \tilde{\mathbf{B}}_i \ln(\mathbf{y}_{it}) \\
&= \tilde{b}_{0i} + \tilde{b}_{1i} \ln W_{Hit} + \tilde{b}_{2i} \ln W_{Lit} + \tilde{b}_{3i} \ln Y_{it} + \tilde{b}_{4i} \ln K_{it} + \tilde{b}_{5i} t \\
&+ .5 \tilde{b}_{11i} (\ln W_{Hit})^2 + \tilde{b}_{12i} \ln W_{Hit} \ln W_{Lit} + \tilde{b}_{13i} \ln W_{Hit} \ln Y_{it} \\
&+ \tilde{b}_{14i} \ln W_{Hit} \ln K_{it} + \tilde{b}_{15i} (\ln W_{Hit}) t + .5 \tilde{b}_{22i} (\ln W_{Lit})^2 \\
&+ \tilde{b}_{23i} \ln W_{Lit} \ln Y_{it} + \tilde{b}_{24i} \ln W_{Lit} \ln K_{it} + \tilde{b}_{25i} (\ln W_{Lit}) t \\
&+ .5 \tilde{b}_{33i} (\ln Y_{it})^2 + \tilde{b}_{34i} \ln Y_{it} \ln K_{it} + \tilde{b}_{35i} (\ln Y_{it}) t + .5 \tilde{b}_{44i} (\ln K_{it})^2 \\
&+ \tilde{b}_{45i} (\ln K_{it}) t + .5 \tilde{b}_{55i} (t)^2,
\end{aligned}$$

where I have imposed the symmetry conditions $\tilde{b}_{ij} = \tilde{b}_{ji}$ for $j \neq i$. From the properties of the logarithmic function, it follows that logarithmic derivation with respect to the high-skilled wage rate yields the cost share equation of high-skilled labour

$$\begin{aligned}
\partial \ln C_{it} / \partial \ln W_{Hit} &= (\partial C_{it} / \partial W_{Hit}) (W_{Hit} / C_{it}) \\
&= H_{it} W_{Hit} / C_{it} \equiv S_{it},
\end{aligned}$$

where the second equality follows from Shepard's Lemma. The cost share of high-skilled labour can thus be written

$$S_{it} = \tilde{b}_{1,i} + \tilde{b}_{11i} \ln W_{Hit} + \tilde{b}_{12i} \ln W_{Lit} + \tilde{b}_{13i} \ln Y_{it} + \tilde{b}_{14i} \ln K_{it} + \tilde{b}_{15i} t. \quad (\text{D.1})$$

Constant returns to scale (*CRS*) in a cost function with capital as a quasi-fixed factor of production is generally defined by (Caves et al., 1981)

$$CRS: \quad 1 = \frac{1 - \partial \ln C_t / \partial \ln K_t}{\partial \ln C_t / \partial \ln Y_t}.$$

In terms of the translog cost function, this implies

$$1 = \frac{1 - \tilde{b}_{4i} - \tilde{b}_{14i} \ln W_{Hit} - \tilde{b}_{24i} \ln W_{Lit} - \tilde{b}_{34i} \ln Y_{it} - \tilde{b}_{44i} \ln K_{it}}{\tilde{b}_{3i} + \tilde{b}_{13i} \ln W_{Hit} + \tilde{b}_{23i} \ln W_{Lit} + \tilde{b}_{33i} \ln Y_{it} + \tilde{b}_{43i} \ln K_{it}},$$

which further yields the *CRS* restrictions

$$\tilde{b}_{3i} + \tilde{b}_{4i} = 1, \quad \tilde{b}_{13i} + \tilde{b}_{14i} = 0, \quad \tilde{b}_{23i} + \tilde{b}_{24i} = 0, \quad \tilde{b}_{33i} + \tilde{b}_{34i} = 0, \quad \tilde{b}_{43i} + \tilde{b}_{44i} = 0.$$

The restrictions implied by price homogeneity follow directly from the definition of price homogeneity: $C(\mu \mathbf{W}, K, Y, t) = \mu C(\mathbf{W}, K, Y, t)$. This condition ensures that the cost-minimising bundle does not change if all prices are multiplied by the same factor μ . In other words, it is only the ratio of input prices that affect the allocation of inputs.

If $\ln C(\mu \mathbf{W}, K, Y, t) = \ln \mu + \ln C(\mathbf{W}, K, Y, t)$ is to hold for the translog cost function, the following restrictions must be imposed: $\tilde{b}_{1i} + \tilde{b}_{2i} = 1$, $\tilde{b}_{11i} = -\tilde{b}_{12i}$, $\tilde{b}_{13i} = -\tilde{b}_{23i}$, $\tilde{b}_{14i} = -\tilde{b}_{24i}$ and $\tilde{b}_{15i} = -\tilde{b}_{25i}$.

The elasticity of substitution evaluated at some central point of the cost share (\hat{S}_i) is given by (see for example Greene (2003, p. 368))

$$\sigma_i \equiv \frac{\partial \ln(H_i/L_i)}{\partial \ln(W_{Li}/W_{Hi})} = 1 + \frac{\tilde{b}_{12i}}{\hat{S}_i(1 - \hat{S}_i)}, \quad (\text{D.2})$$

Imposing both price homogeneity ($\tilde{b}_{11i} = -\tilde{b}_{12i}$) and constant returns to scale ($-\tilde{b}_{13i} = \tilde{b}_{14i}$), and using the relationships $b_{0i} = \tilde{b}_{1i}$, $b_{1i} = \tilde{b}_{15i}$, $b_{2i} = \tilde{b}_{11i}$ and $b_{3i} = \tilde{b}_{14i}$ to the cost share equation (D.1) and the elasticity of substitution (D.2) yields the specifications used in the paper

$$S_{it} = b_{0i} + b_{1i}t + b_{2i} \ln(W_H/W_L)_{it} + b_{3i} \ln(K/Y)_{it},$$

$$\sigma_i = 1 - \frac{b_{2i}}{\hat{S}_i(1 - \hat{S}_i)}.$$

D.2 Additional tables

TABLE D.1: VEqCM: test of the cointegration rank (Trace test).

H_0 : No. of cointegrating equations	0	≤ 1	≤ 2
Sector, i	$\hat{\lambda}_1$	$\hat{\lambda}_2$	$\hat{\lambda}_3$
15 Consumption goods	0.41	0.29	0.12
25 Misc. manufacturing	0.83**	0.62**	0.21
30 Energy intensive manufact.	0.80**	0.58**	0.17
45 Engineering products	0.45	0.28	0.20
50 Oil platforms and ships	0.57**	0.45**	0.35**
55 Construction	0.52*	0.28	0.21
63 Financial intermediates	0.74**	0.51**	0.13
64 Oil and gas exploration	0.85**	0.41**	0.30*
71 Electricity	0.70**	0.40	0.14
74 Domestic transportation	0.38	0.26	0.18
81 Wholesale and retail trade	0.36	0.30	0.24
85 Other private services	0.58**	0.41*	0.19

Rejection at the 10 per cent significance level is indicated with * and ** indicates rejection at the 5 per cent significance level using Mackinnon-Haug-Michelis p-values.

TABLE D.2: VEqCM: Test for autocorrelation

	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6
15 Consumption goods	9.66 (0.38)	7.95 (0.54)	8.19 (0.52)	5.27 (0.81)	5.97 (0.74)	9.90 (0.36)
25 Misc. manufacturing	17.40** (0.04)	11.98 (0.21)	2.78 (0.97)	8.92 (0.44)	5.18 (0.82)	5.72 (0.77)
30 Energy intensive manufacturing	11.61 (0.24)	11.23 (0.26)	6.30 (0.71)	3.01 (0.96)	10.54 (0.31)	8.86 (0.45)
45 Engineering products	6.79 (0.66)	7.68 (0.57)	8.11 (0.52)	5.65 (0.77)	8.12 (0.52)	4.91 (0.84)
50 Oil platforms and ships	3.78 (0.93)	12.72 (0.18)	9.03 (0.43)	6.18 (0.72)	18.31** (0.03)	8.63 (0.47)
55 Construction	8.04 (0.53)	9.65 (0.38)	4.56 (0.87)	7.84 (0.55)	9.61 (0.38)	8.34 (0.50)
63 Financial intermediates	23.66** (0.00)	24.51** (0.00)	7.55 (0.58)	7.07 (0.63)	6.54 (0.68)	7.90 (0.54)
64 Oil and gas exploration	12.44 (0.19)	12.33 (0.20)	11.07 (0.27)	5.77 (0.76)	7.05 (0.63)	8.26 (0.51)
71 Electricity	9.70 (0.38)	7.15 (0.62)	17.03** (0.05)	8.14 (0.52)	8.76 (0.46)	6.95 (0.64)
74 Domestic transportation	9.31 (0.41)	7.14 (0.62)	1.89 (0.99)	4.32 (0.89)	8.42 (0.49)	5.53 (0.79)
81 Wholesale and retail trade	3.36 (0.95)	5.73 (0.77)	4.16 (0.90)	5.93 (0.75)	2.00 (0.99)	4.85 (0.85)
85 Other private services	9.52 (0.39)	5.26 (0.81)	3.48 (0.94)	9.72 (0.37)	3.82 (0.92)	8.92 (0.44)

Probability of rejecting the null hypothesis of no serial autocorrelation is given in brackets. Rejection at the 10 per cent significance level is indicated with * and ** indicates rejection at the 5 per cent significance level.

